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BROWN BOVERI REVIEW

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View of the Baden factory area of Brown, Boveri & Co., Ltd.

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The new factory at Birr where Brown Boveri now make large electrical machines

THE BROWN BOVERI REVIEW

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Review of Technical Progress in the Years 1959/60

THOUGH SURROUNDED on all sides by tempestuous technical advances, electrical engineering has managed to maintain its key position in every respect by also developing in the same restless manner. The leading part played by electricity is largely the result of the characteristic close combination of its versatility, in being employable in any place, and the ease with which it can be conveyed there in suitable form. But electricity is not only a source of power in the conventional sense, it may also be the bearer of all kinds of signals. The fact that a third property, i.e. the storage of electricity, though feasible in principle, has never been realized in practice has not succeeded in holding up its victorious progress to any great extent.

In our work, the results of which form the subject of the following traditional biennial review, our main efforts have been centred on electrical engineering, regardless of the great importance attached, not only to the thermal prime movers of large electric generators, but indeed to all high-speed rotating thermodynamic machines.

Technical development, which will always be the most noble task for engineers, has to be directed along various lines. One of these is to increase unit outputs and operating voltages, with due regard to economic requirements, in most cases leading to an increase in the size of individual products and, in consequence, to the occasional erection of new, larger factory premises.

Another line of development is the replacement of certain functional elements by superior elements, without having to make any marked change in the basic conception. A development of this kind has been taking place for many years in the sphere of equipment for converting alternating into direct current where, successively, the motor-generator has given way to the rotary converter, then to the mercury-arc rectifier or mutator, then the mechanical or contact rectifier and, lastly, to the semiconductor rectifier, in spite of the fact that each in its time achieved considerable technical success. Though each was designed as an alternative to its predecessor, each in turn proved to offer such inherent advantages that it led to a development of the entire field in this particular case. Another example is control engineering, where electronic devices are slowly but surely superseding all other known means, with the result that the original field of applications has been expanded to a wide range of other tasks.

The third line cannot be covered in a review of completed achievements, but it nevertheless plays an increasingly vital role in technical research work. Its goal is the exploitation of new spheres which at present do not appear to be even remotely beneficial to our everyday business life, but which cannot be neglected as the future of an undertaking may be dependent on them in years to come. In this category we include not only such subjects as nuclear fission and fusion, but also fuel cells, thermo-electric elements, thermo-ionic processes and magneto-hydrodynamic machines in which heat is converted directly into electricity. Whether any one of these will ever mature to industrial significance cannot be reliably foreseen yet. This observation is merely included as a reminder that the activity of a research organization, even though it has a purely industrial character, must be directed towards securing not only our present livelihood, but also our future.

(KME)

T. BOVERI

I. POWER GENERATION

A. Thermal Machines

The intention of the present review is only to recall a few of the outstanding successes achieved during the last two years, since these have already been reported in detail in various special numbers. Although it is not desired to report the same information twice, it seems appropriate at least to enumerate these successes.

In the January/February issue of the Brown Boveri Review, 1960, details were furnished of the two single-shaft turbosets, each having a rated output of 230 MW, for the City of Los Angeles. The same issue also included a description of the cross-compound type turbo-alternator set having more than twice the output, i.e. 550 MW, for the Tennessee Valley Authority, U.S.A. (Fig. 1). These, which are being built, and even larger turbines embody the proved Brown Boveri reheat design; so far 71 such machines have been or are being manufactured. The largest steam turbine of this kind delivered in the past year is the 175-MW set for the Amer power station belonging to the Noordbrabantsche Electriciteits Mij., Geertruidenberg, Holland. The colour plate I shows this turbine on the test bed in Baden.

Also with gas turbines the aim is towards greater efficiency. The previously mentioned Brown Boveri Review No. 1/2 1960, reported about gas turbines for an inlet temperature of 750 °C. Fundamentally interesting possibilities for improving the thermal efficiency are offered by combining gas and steam turbines. A clarification of the prospects for this solution was published in Brown Boveri Review No. 12, in December 1960. Attention was also drawn to the installations at Dudelange (Luxembourg), Korneuburg (Austria), and Bremen (Germany), which are already in operation. The Company also feels justified in drawing attention to Velox boilers whose charging sets have for years supplied notable quantities of electrical energy into the supply network; these boilers were the forerunners of combined installations.

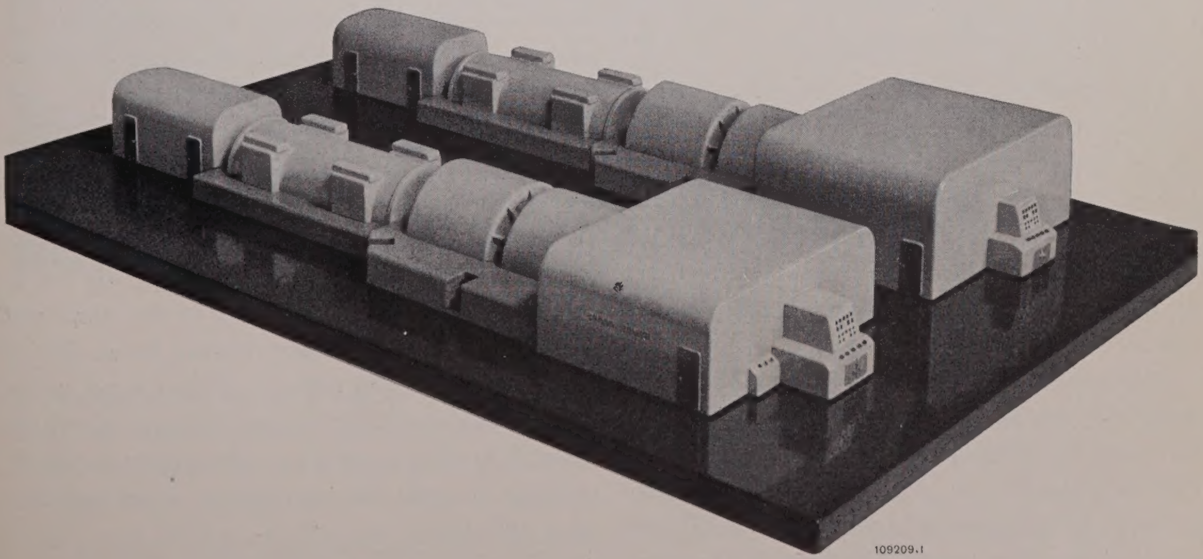


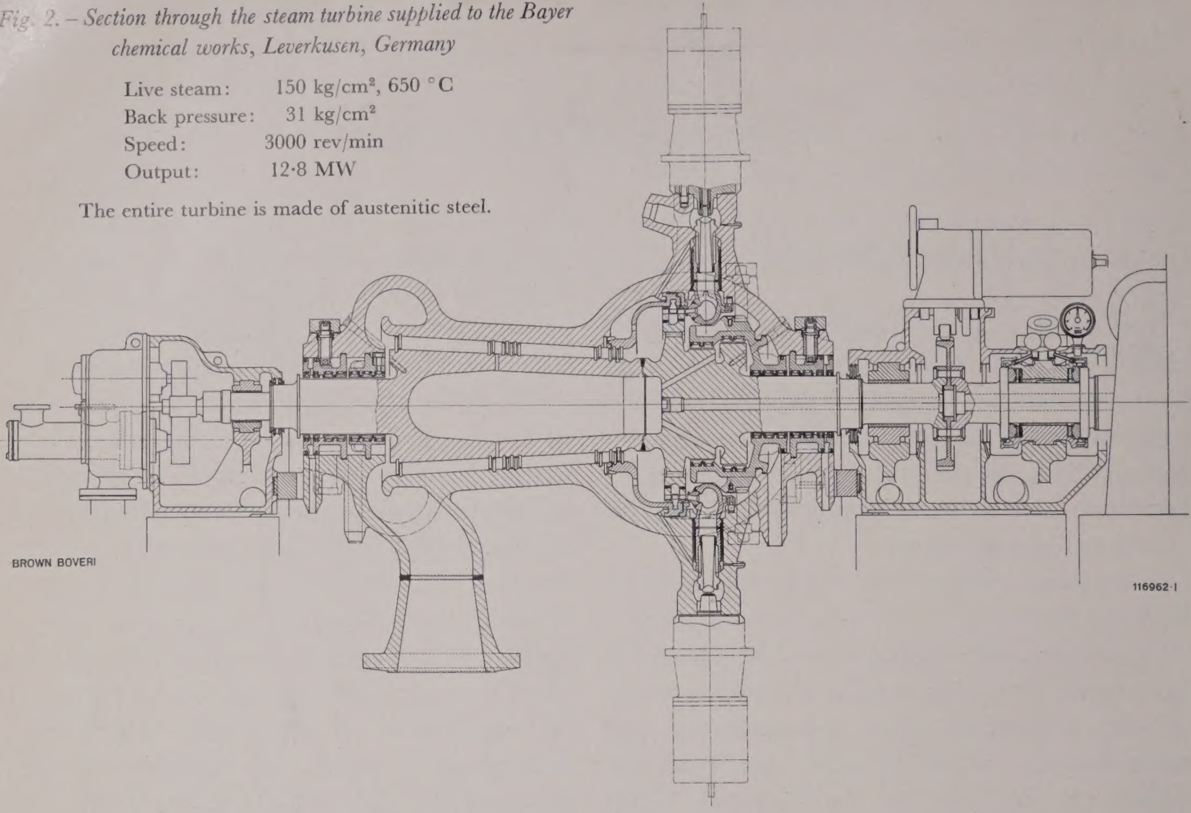
Fig. 1. – Model of the 500-MW turboset being built in Baden for the Tennessee Valley Authority (USA)

The total output is divided approximately equally between the two shafts, which run at a speed of 3600 rev/min.

Fig. 2. – Section through the steam turbine supplied to the Bayer chemical works, Leverkusen, Germany

Live steam: 150 kg/cm², 650 °C
Back pressure: 31 kg/cm²
Speed: 3000 rev/min
Output: 12·8 MW

The entire turbine is made of austenitic steel.



Looking into the more distant future, one recognizes progress of a fundamental nature, when the direct conversion of heat to electricity will be economically possible. In the meantime, the study of these problems has been commenced.

1. Steam Turbines

The last two years have brought considerable progress in the development of steam turbines.[1] The unit output of the largest turbosets being built has been trebled during this period. Investigations concerning even larger outputs are in progress, also for still higher steam conditions. This review is devoted to a series of turbines of high temperatures and pressures, which will be important for the future.

The first of these turbines was ordered from Brown Boveri by the Bayer chemical works, Leverkusen, Germany. The live steam conditions were 150 kg/cm² (147 bar) and 650 °C, the back pressure 31 kg/cm² (30·4 bar). They have an output of 12·8 MW. At the time the order was placed, when it was necessary to decide design details, the Company mainly had experience of single-shell turbines. It was therefore decided not to retain the proved single-shell design, but to manufacture the entire turbine of austenitic material. At the same time the turbine was designed for a live steam temperature of 650 °C, which was visualized for future extensions of the power station involved. This temperature was reasonable because in the case of austenitic material the drop in strength values between 600 °C and 650 °C is relatively small.

1200°F

Fig. 2 shows a section through the turbine, the pictures Fig. 3 and 4 were taken during erection in the factory. The design is similar to that employed for the high-pressure casing of small Brown Boveri reheat turbines. The diffusers of the control valves act as hollow bolts and secure the nozzle boxes; the impulse blading is welded on. During manufacture, welding the austenitic steel casting caused considerable difficulty.[2]

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[1] P. HUMMEL, R. NOSER: Large turbosets for the United States. Brown Boveri Rev. 1960, Vol. 47, No. 1/2, p. 6–16.

[2] A. LÜTHY: Quelques considérations relatives au soudage des aciers alliés, utilisés dans la construction des machines thermiques modernes. Rev. Soud. Techn. connexe 10 (1956), p. 117–31.

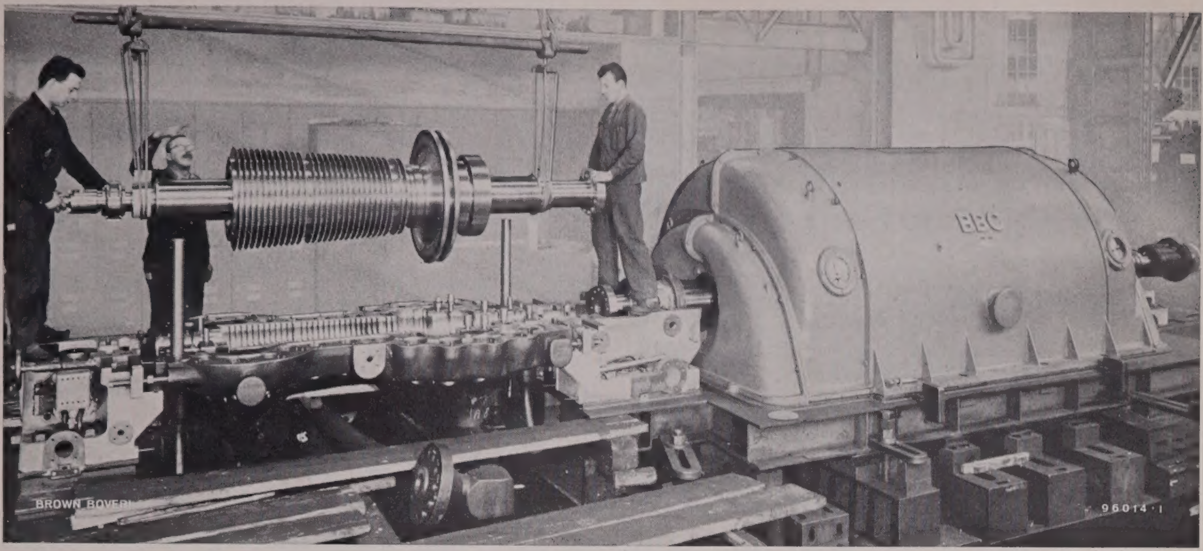


Fig. 3. – Lowering the shaft into the casing of the steam turbine for Leverkusen

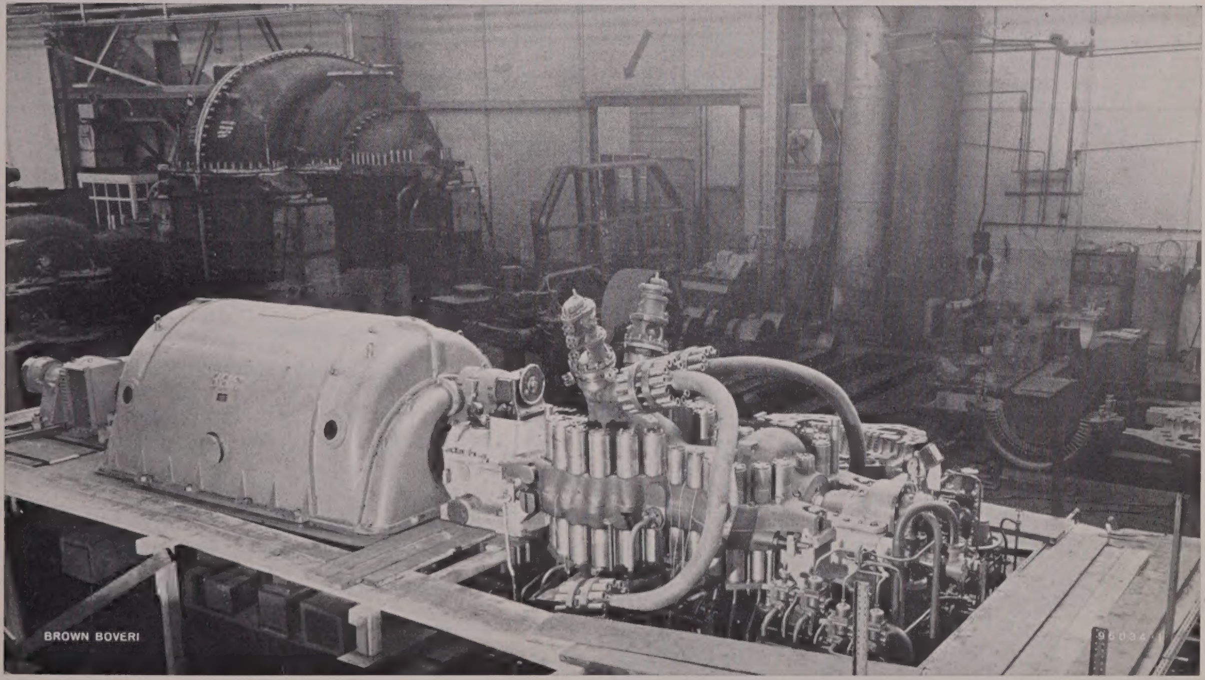


Fig. 4. – The turbine in Fig. 2, completely erected and ready for a trial run

The machine was taken into service in October 1957, but after 285 hours it suffered blading damage which became evident as a sudden increase in the vibrations from an amplitude of 2 to 12 μ. It was found that a pair of blades had broken off the first blade ring. The two detached blades had no space to escape and were consequently ground to pieces. The remainder of the impulse blading, however, was hardly damaged; this testifies to the robustness of the welded-on blades. The natural frequency of the blading was corrected by thickening the blade ring. The turbine has given no further trouble since March 1958. At the start the machine operated with a live-steam temperature of 600 to 610 °C and since the first overhaul in May 1960, after 12 700 hours of duty, with a temperature of 650 °C.

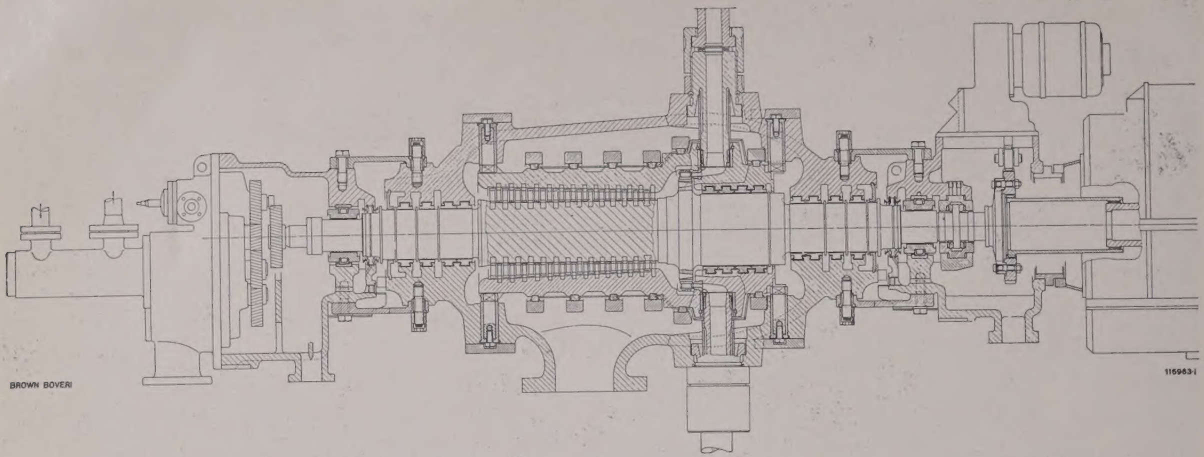


Fig. 5. – Section through the turbine supplied to Margam

Live steam: 3000 lb/in², 1050 °F Back pressure: 660 lb/in² (45·7 bar) Speed: 9500 rev/min Rated output: 9·5 MW

Meanwhile, it became evident that such an extensive employment of austenitic material did not provide an ideal solution. Apart from the technical disadvantages of this metal, low elastic limit and poor heat conducting properties, combined with consequently long heating-up periods, it is primarily the price which opposed its use. The Company therefore strove to find a design which rendered the employment of large austenitic pieces unnecessary even for temperatures up to 650 °C; only valves, nozzle boxes and blading would be made, in part, of austenitic material. Two turbines embodying this principle are now in operation, although the operating temperatures are relatively low, so that, apart from a few blades, there are no parts made of austenitic material.

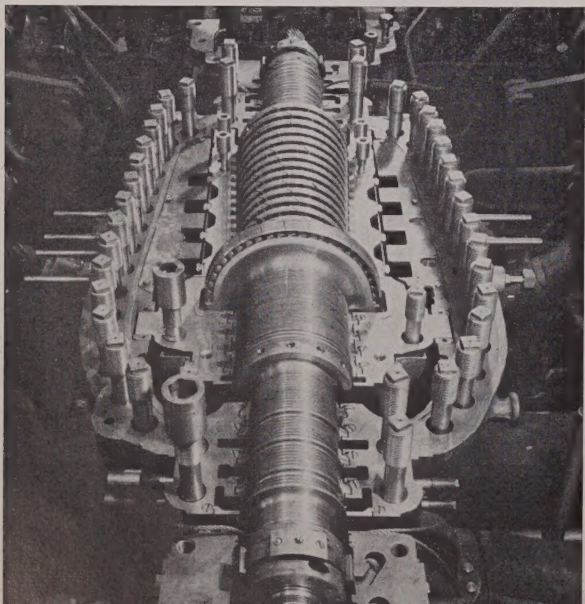


Fig. 6. – The turbine supplied to Margam

During erection in the works, checking the clearance of the inner shell.

The first turbine, a high-speed back-pressure machine, for 3000 lb/in², 1050 °F (208 bar, 565 °C) rated 9·5 MW, 9500 rev/min, was built under licence by Richardsons Westgarth Ltd., Hartlepool, England, for the Steel Company of Wales, for duty in the Margam B power station. Fig. 5 shows the essentials of this new design. The casing consists of an inner shell held together by shrunk rings, and an outer shell which is only exposed to the exhaust-steam pressure of 45·7 bar. A normal double-shell design is therefore employed, with the sole distinction that the studs on the inner shell are replaced by shrunk rings. These are exposed to a temperature approaching that of the relatively cool exhaust steam and are therefore made from ordinary Cr-Mo-V steel, which has a high strength at this temperature. In this way it is easily possible to overcome the pressure differences occurring at the inner shell. The latter, which owing to the compactness of the turbine is not provided with separate nozzle boxes, is made of 12% chrome cast steel. Erection (Fig. 6) is precisely the same as for a normal double-shell turbine; the blade clearances can be checked with the inner shell in its final position. After this operation, the shell is closed by means of a few bolts; it is then fixed with respect to the shaft and withdrawn together with the latter in order to shrink on the rings (Fig. 7 and 8). After the shrinking-on process, the inner shell is replaced on the unaltered supporting surface in the outer shell. Another new feature of this turbine is the connection of the outer shell with the bearing pedestals by means of four identical plates (Fig. 5) which, owing to their symmetrical arrangement, assure that the casing and the shaft are co-axial. The radial expansion of the hot casing distorts the plates elastically, but the connection is extremely rigid with respect to every other movement.

The valve chests are installed near the turbine; a plate separates the parts conducting oil from the parts conducting steam. The live-steam pipework is secured to the valve chests and the turbine by means of screwed high-pressure joints (Fig. 9). Cylindrical keys bridge the separating surface and transfer the twisting moments occurring in almost every pipe. A sealing diaphragm is provided, in order to seal-weld the connection completely; during the trial run a metal-asbestos gasket was employed. A powerful tensioning device enables even pre-tensioned pipes, twisted in opposite directions, to be brought together again, so that screwed joints can be made. The Company now extensively uses such screwed joints instead of flanges. The turbine at Margam has been in operation since May 1960.

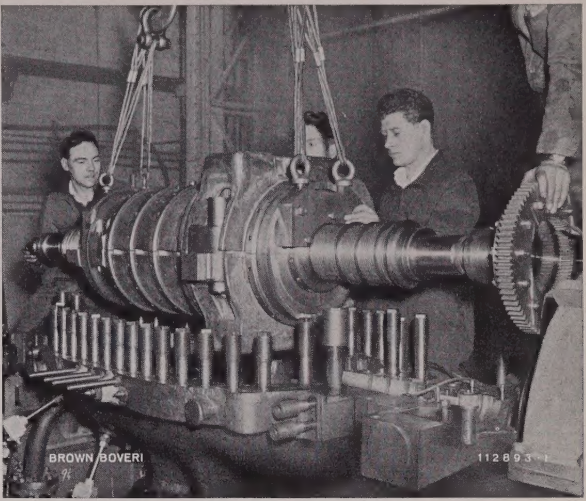


Fig. 7. – The turbine for Margam

Removing the shaft and inner shell to shrink on the rings.

A second turbine of this type was built by Brown Boveri, Mannheim, for the Hüls Chemical Works in Germany. The plant is operated with live steam at 300 kg/cm² (294 bar), 555 °C, with reheat at 100/92 kg/cm² (98/90 bar) to 530 °C, and with a back pressure of 26 kg/cm² (25·15 bar). The turbine is provided with two cylinders, and the condition was made that it must be possible to disconnect the shaft of the highest pressure section and run the turbine with the remaining sections. The installation operates with variable pressure so that it was possible to dispense with a regulating stage and to equip the turbine with purely reaction blading (Fig. 10). The large number of stages is determined by the small steam volume necessary for a turbine running at 3000 rev/min. As for the Margam plant, the blades were made in one piece with the shroud plate. In this case, too, the inner shell of the first cylinder is held together with shrunk rings which absorb the pressure difference of 200 kg/cm² (196 bar). All the parts conducting live steam, the inner shell and shaft, are built of heat-resisting, 12% Cr steel. Owing to the welded drum design the apparently slender shafts run below the critical speed. In principle, the connection between the outer shell and the bearing

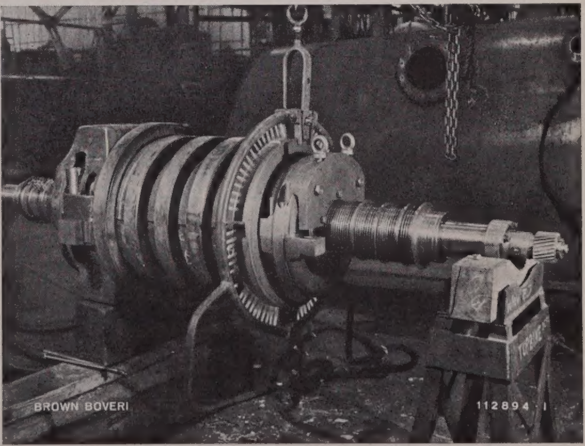


Fig. 8. – Turbine for Margam

Shrinking on the rings.

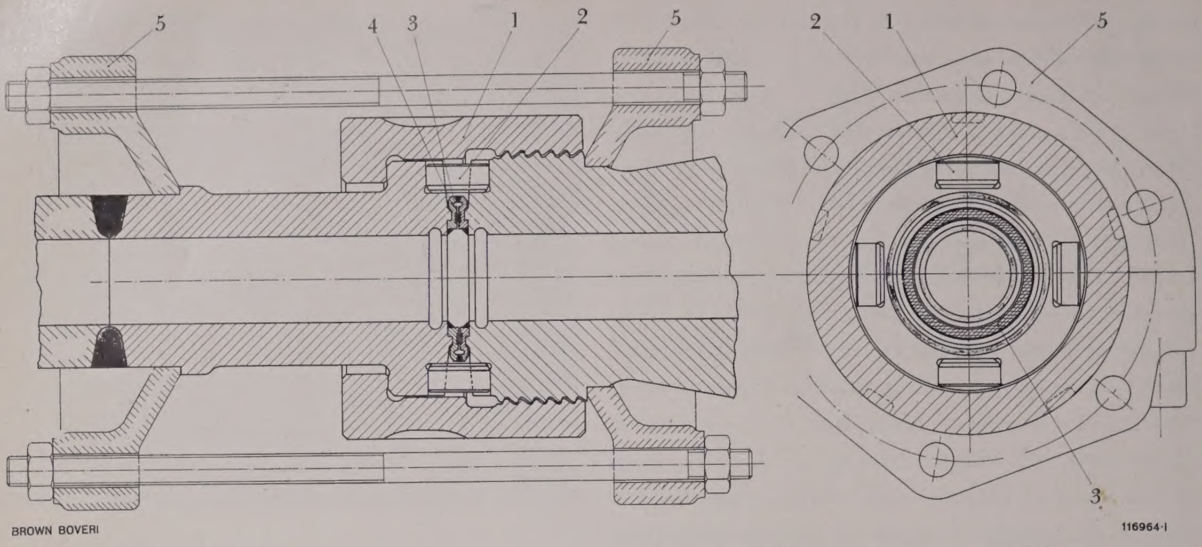


Fig. 9. – Screwed joints for high pressure

1 = Skirted nut 2 = Cylindrical keys opposing twist 3 = Metal-asbestos gasket 4 = Sealing diaphragm 5 = Tensioning device

pedestal is similar in design to that of the Margam turbine, although the uppermost plates are dispensed with to enable the bearing cover to be opened easily. The plates of the bearing pedestal are secured with adjustable positioning pins enabling each bearing to be readily adjusted. The centre bearing pedestal stands firmly on the foundation while the front and back pedestals slide with the turbine. Fig. 11 to 13 illustrate the machine during various stages of manufacture.

It is hoped that this glimpse of the Company's development work in the sphere of steam turbines will prove that Brown Boveri are well equipped to deal with future problems. The employment of higher

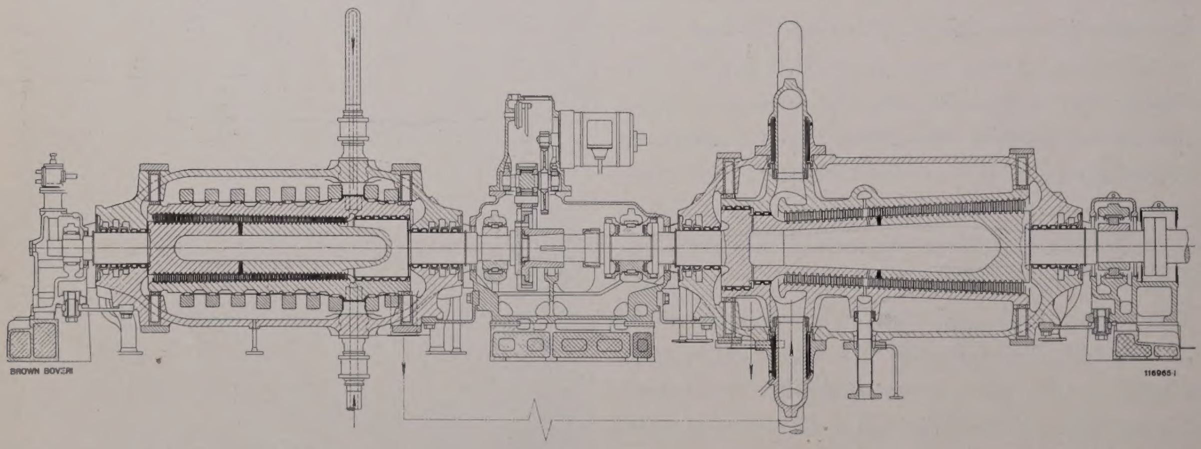
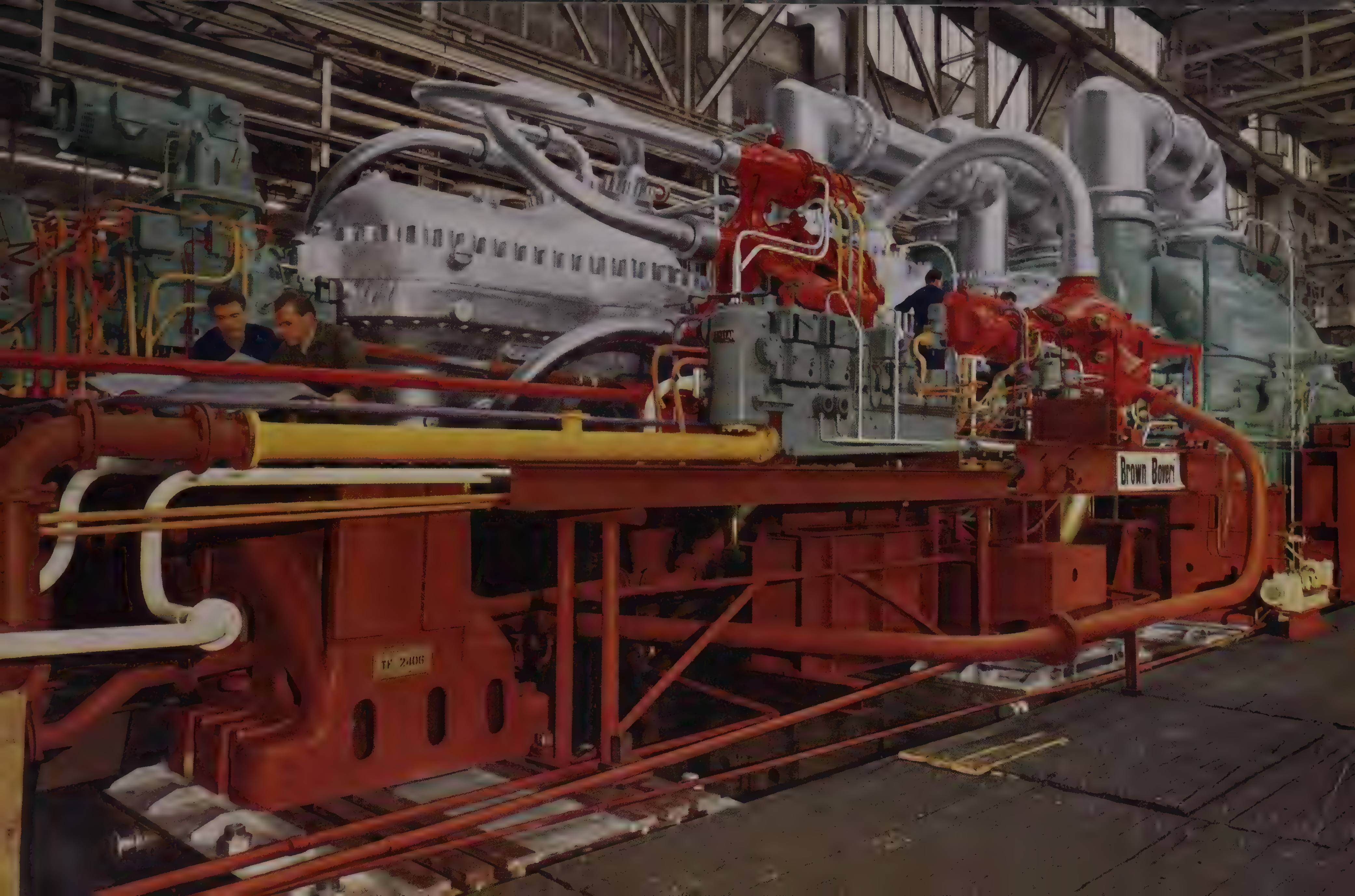


Fig. 10. – Section through the Hüls turbine, rated 36 MW

Live steam: 300 kg/cm², 555 °C Reheat to: 530 °C at 92 kg/cm² Back pressure: 26 kg/cm² Speed: 3000 rev/min

Colour plate I – The largest steam turbine yet completed by the Company, having an output of 175 MW at a speed of 3000 rev/min

This turbine is for the Amer power station belonging to the Provinciale Noordbrabantsche Electriciteits Mij., Geertruidenberg, Holland. Here the machine is seen on the test-bed in the Baden works. ▶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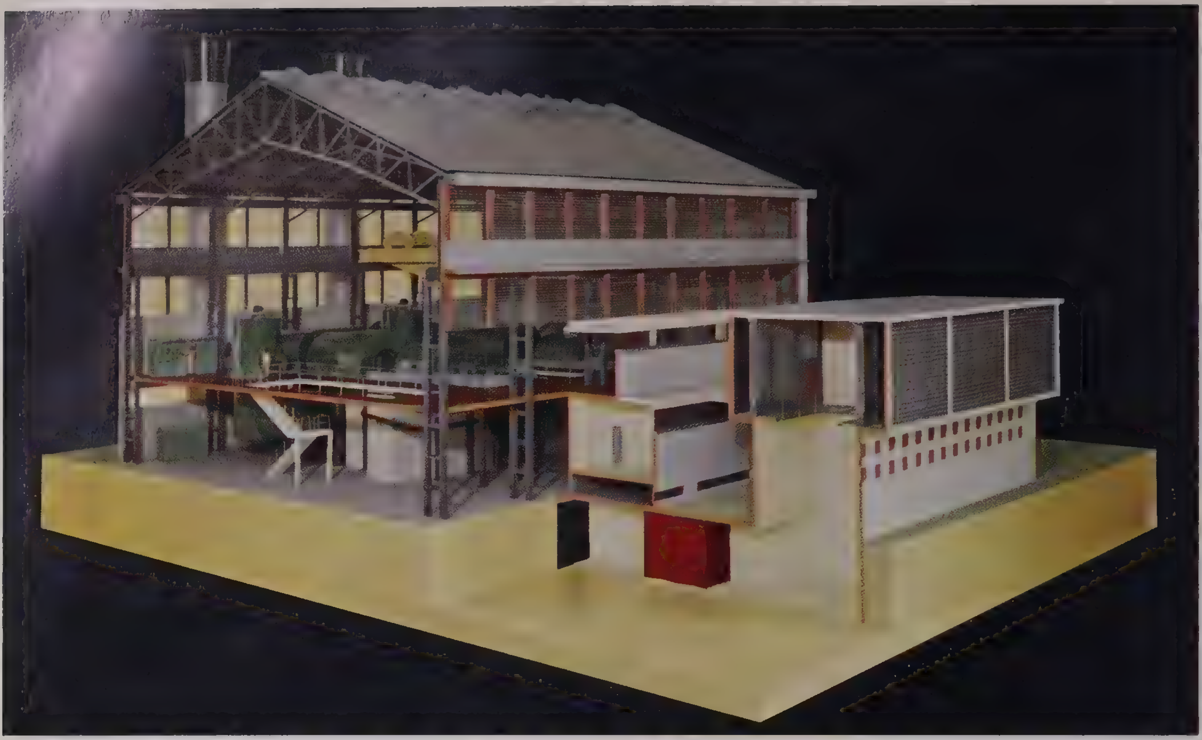
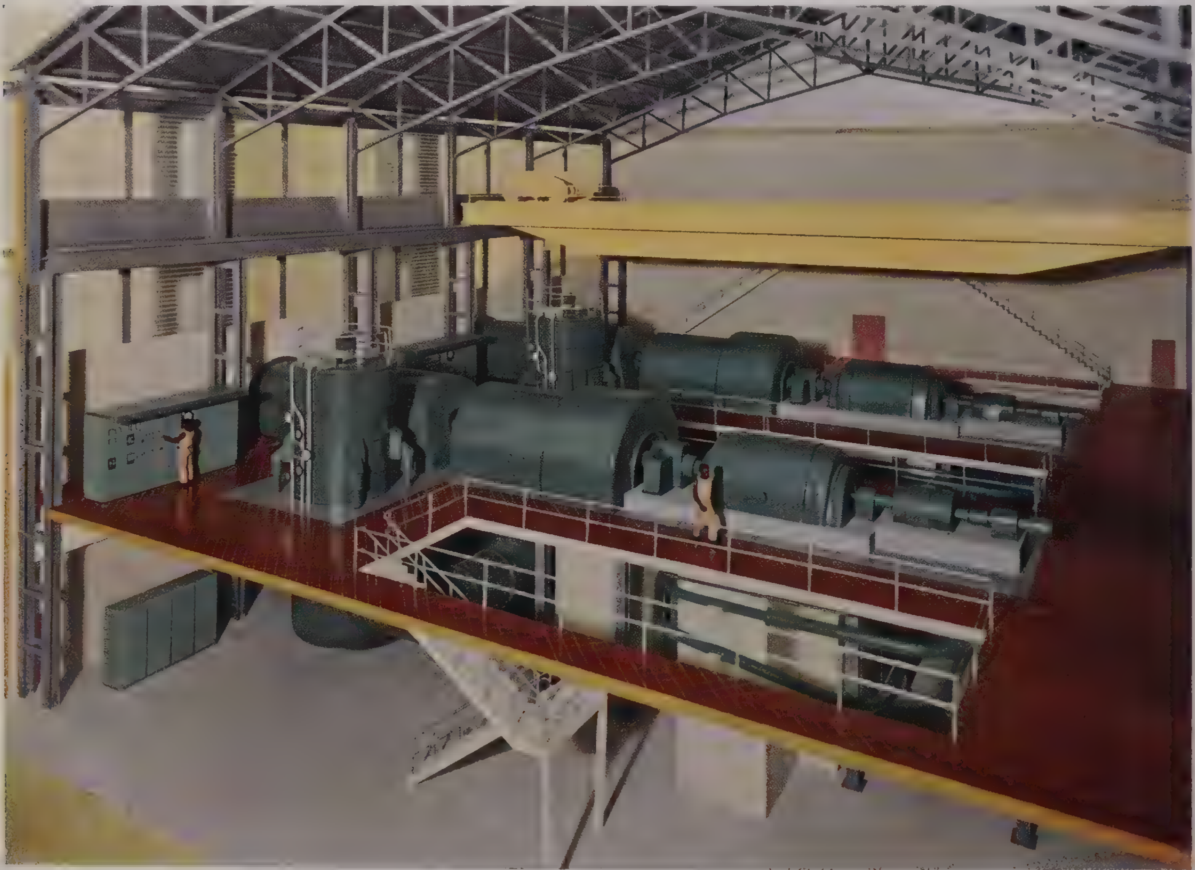


II

Model of the Afam gas-turbine power station in East Nigeria

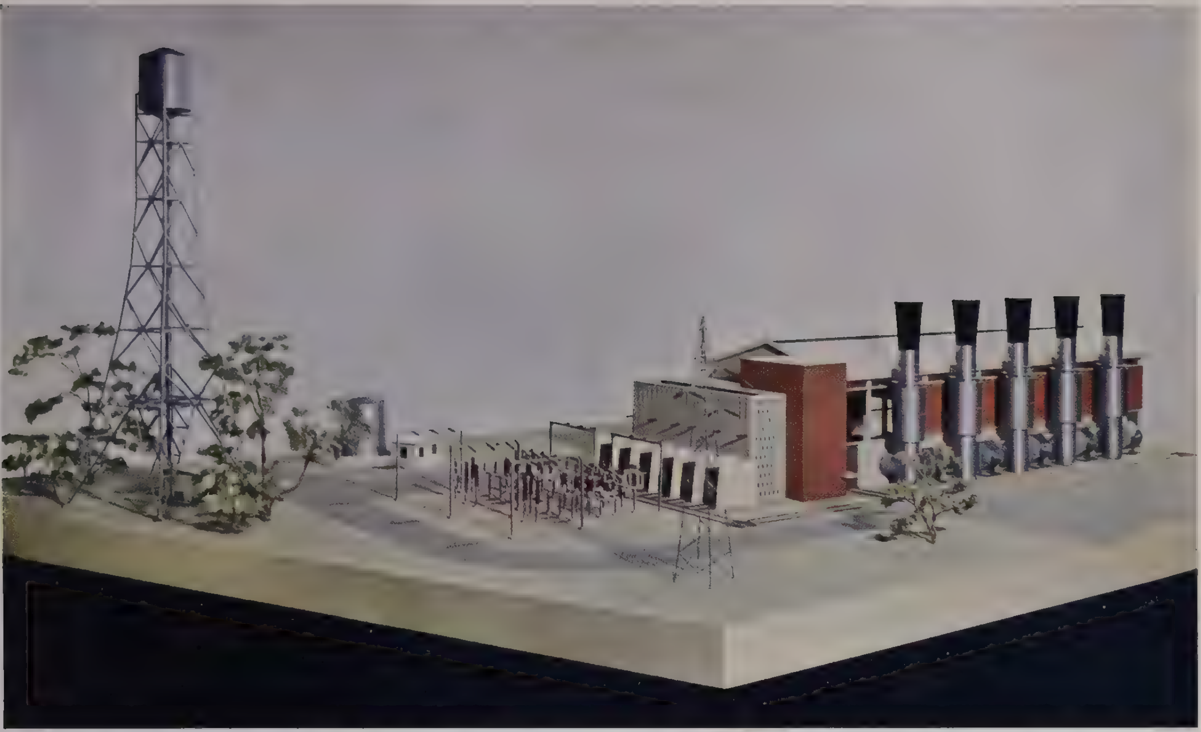
Exterior view: showing the air filtration annexe in front of the power plant with two 10-MW gas-turbine sets.



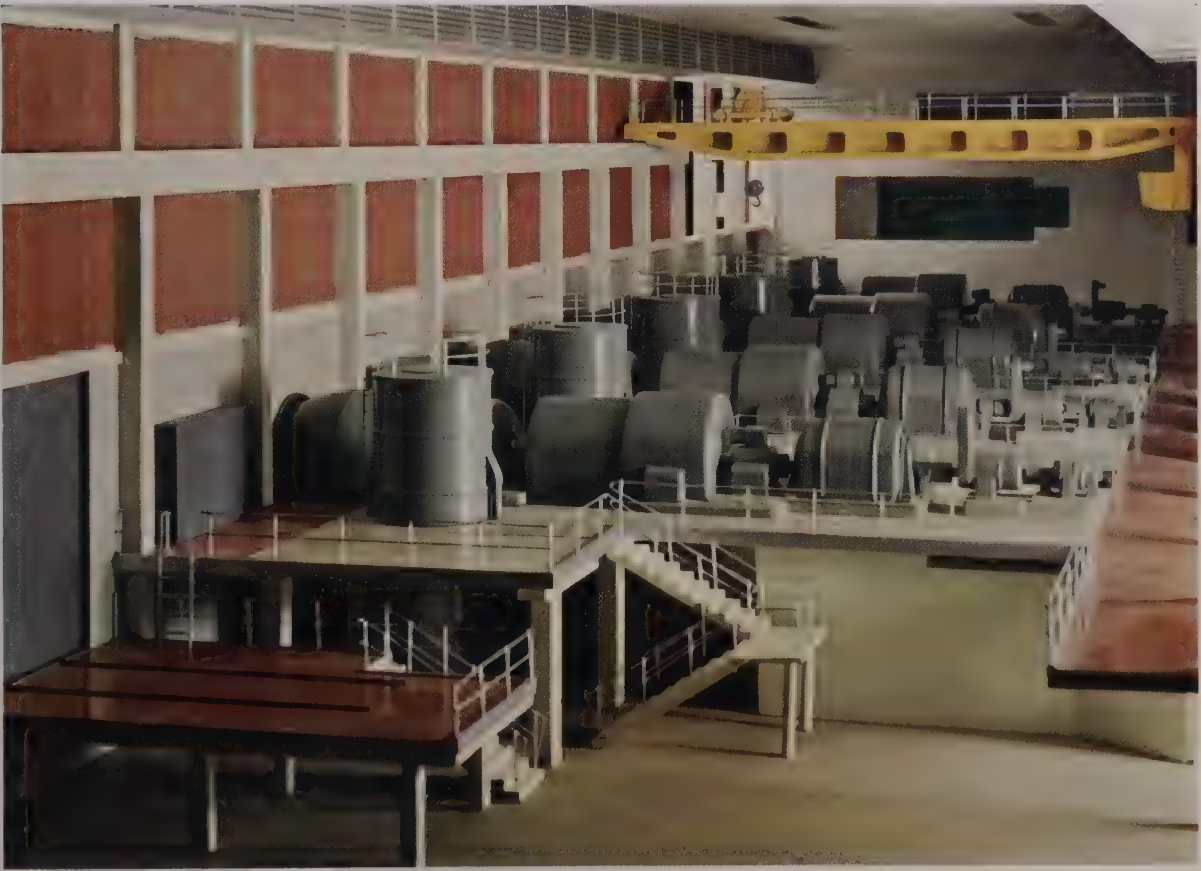
III

Model of the Afam gas-turbine power station in East Nigeria

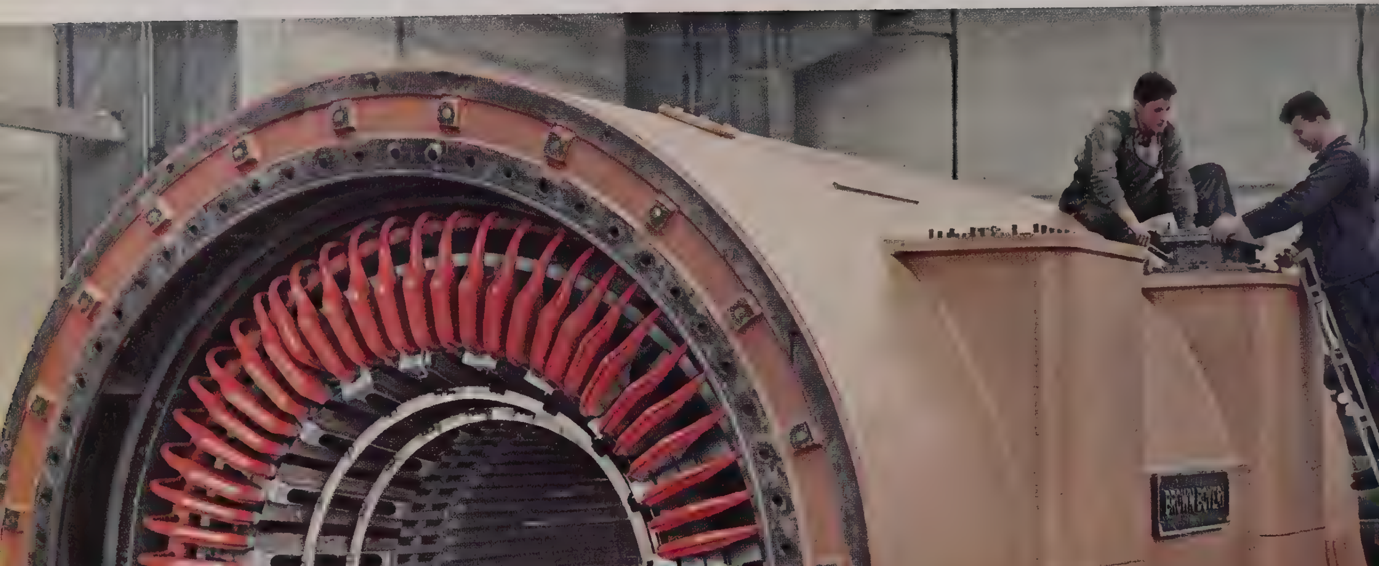
Interior view of the power plant with the two 10-MW single-shaft gas-turbine sets.



IV *Model of the 30-MW gas-turbine power station at Tibu, Colombia*
General view, showing the outdoor transformers and switchgear, the fuel tank and water-tower.



V *Model of the 30-MW gas-turbine power station at Tibu, Colombia*
Indoor view, showing the five turbosets which the station will contain when finished.

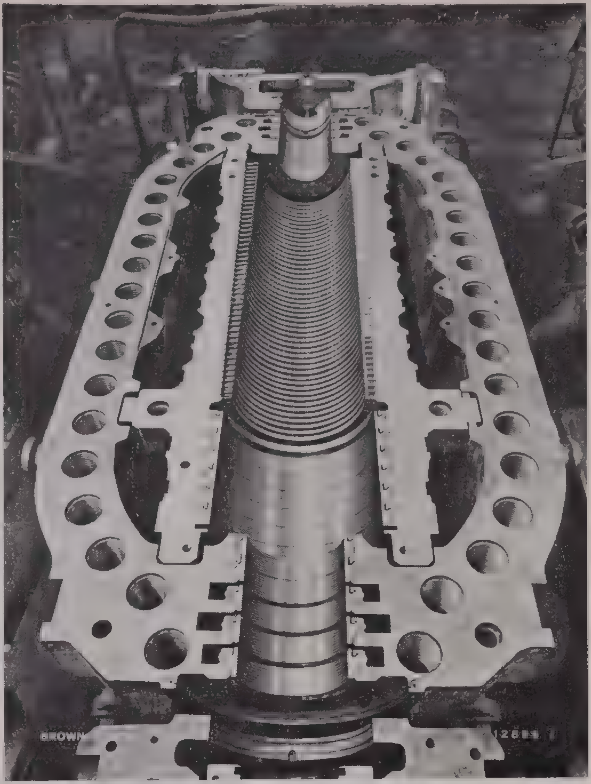


VI *164-MVA generator for 3000 rev/min, p.f. 0·8, for Harculo power station of the IJsselcentrale Zwolle*

The stator winding is cooled with oil which enters through the hoses visible in the picture and leaves through similar hoses at the opposite end.

Fig. 11. – Erection of the Hüls turbine in the works

Lower halves of the first cylinder.



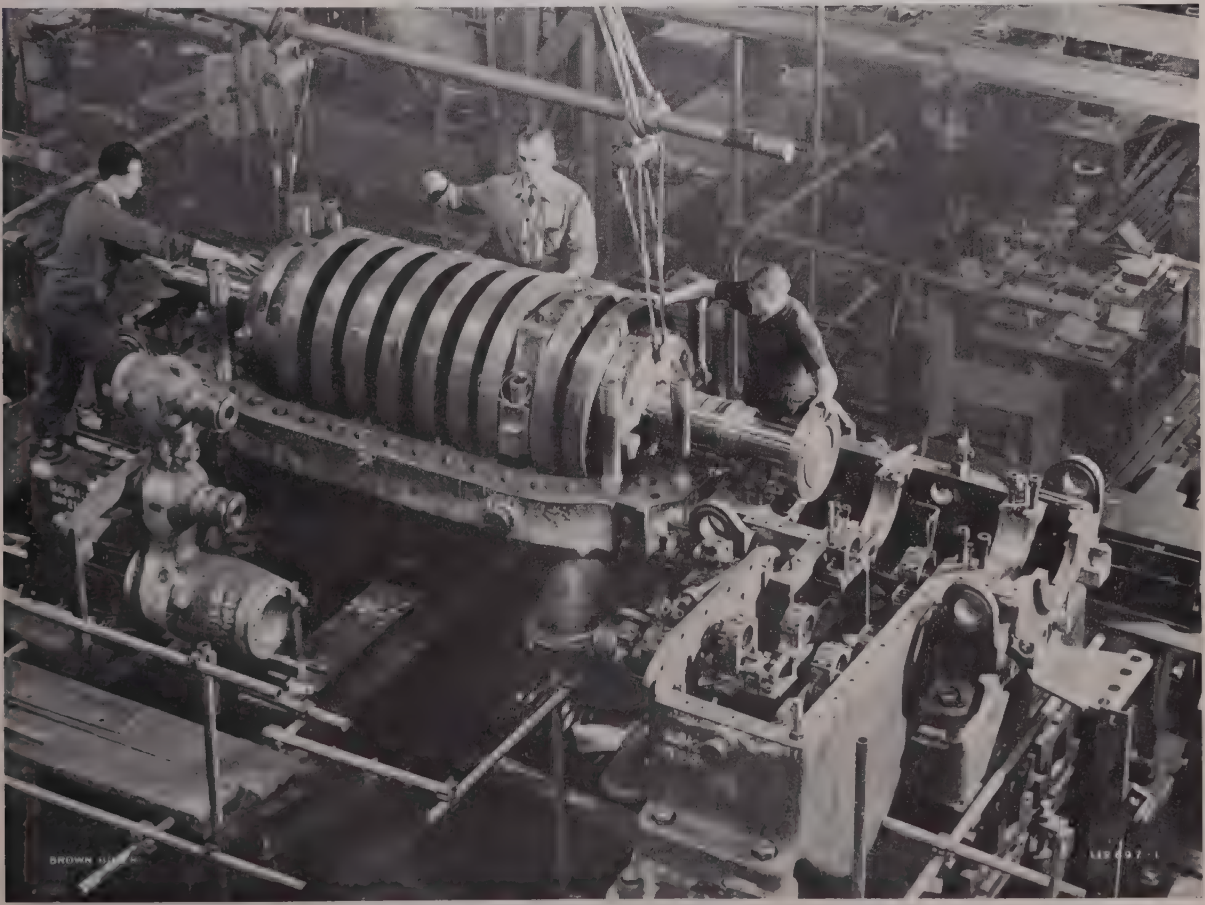
pressures and temperatures is bound to extend—particularly for very high output machines. The design of such turbines is based on the experience gained with the equipment described here.

2. Steam Power Stations

Following the order received from the Italian electricity companies, Società Elettrica Selt-Valdarno and Società Romana di Elettricità in 1955 for the thermal power station of Santa Barbara, near Florence, the Società Selt-Valdarno placed an order

Fig. 12. – Turbine for Hüls; inner shell with shrunk rings and the shaft

One of the two valve chests can be seen in the left foreground.



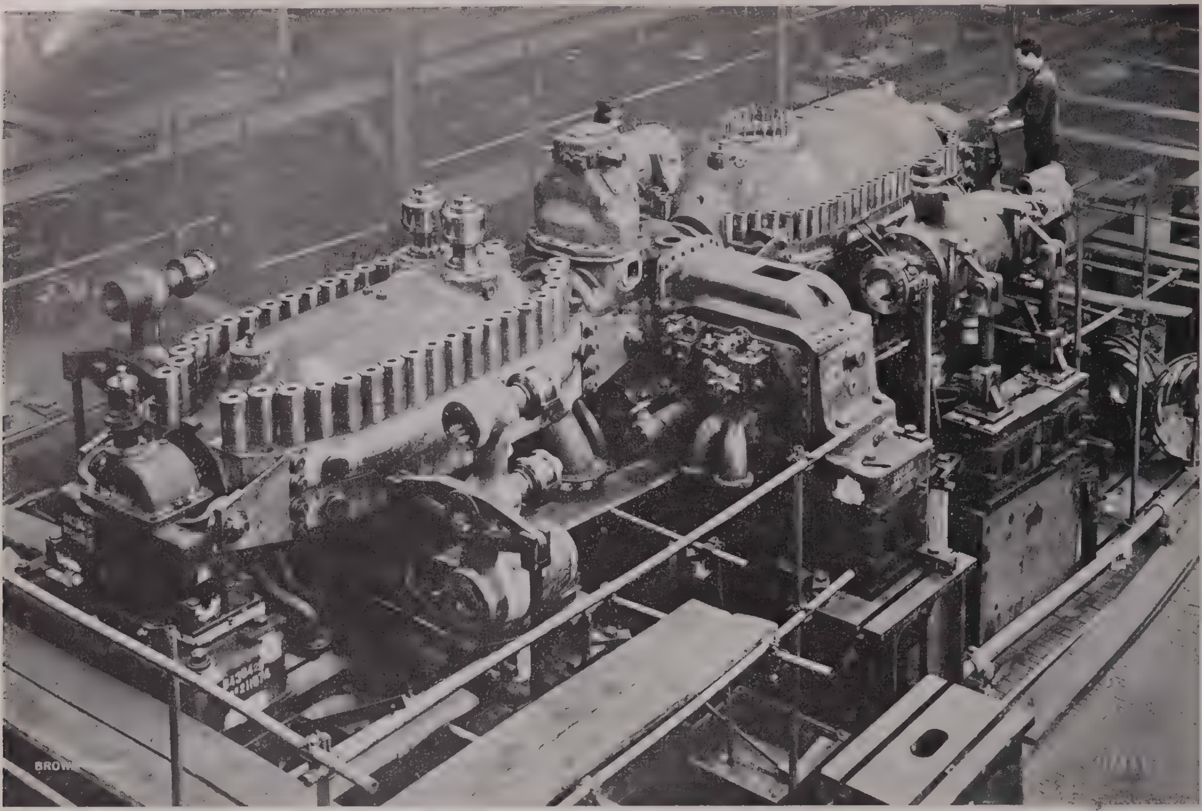


Fig. 13. – Erecting the Hüls turbine in the works

The connection between the turbine and the bearing pedestal by means of flexible plates is clearly recognizable.

with the Company in 1959 for the equipment in the new steam power station in Leghorn (Fig. 14).

Ultimately, two turbo-alternator sets, totalling 152 MW, are visualized for this power station. The first set, which Brown Boveri has been instructed to supply, is designed for live steam at 145 kg/cm^2 (142 bar), 535 °C and reheat to 535 °C. The boiler is oil-fired, but a later conversion to pulverized fuel is planned. For the first few years it is intended to start up the plant early every morning and to shut it down late in the evening: the machine is designed for this kind of operation.

As for the Santa Barbara power station, the project work for this installation was entrusted to Brown Boveri.

The choice of *condensing and feed-heating plant* is of primary importance for a steam power station. Correct dimensioning of this equipment and its layout has the same economic significance as the results of flow investigations in turbines. It was therefore very rewarding to subject the technique associated with these components to a thorough scientific investigation. During an investigation such as this, considerable importance is attached to the metallurgical problems.

The largest *Brown Boveri condenser* so far was designed for the Amer power station belonging to the N.V. Provinciale Noordbrabantsche Electriciteits Maatschappij. This condenser has a total surface of 9000 m^2 and contains no less than 17 200 tubes 7 m long. For standard tube lengths up to 11 m it would be possible to build a condenser employing the same design for a turbine output of 240/275 MW. Space problems made it necessary to build a relatively short condenser, and the number of tubes was increased accordingly. Fig. 15 shows the water inlet and outlet ends of the two-pass condenser. It is noticeable here that the outlet connections from the lower part of the water box are led downwards. This arrangement conduces to a very favourable layout

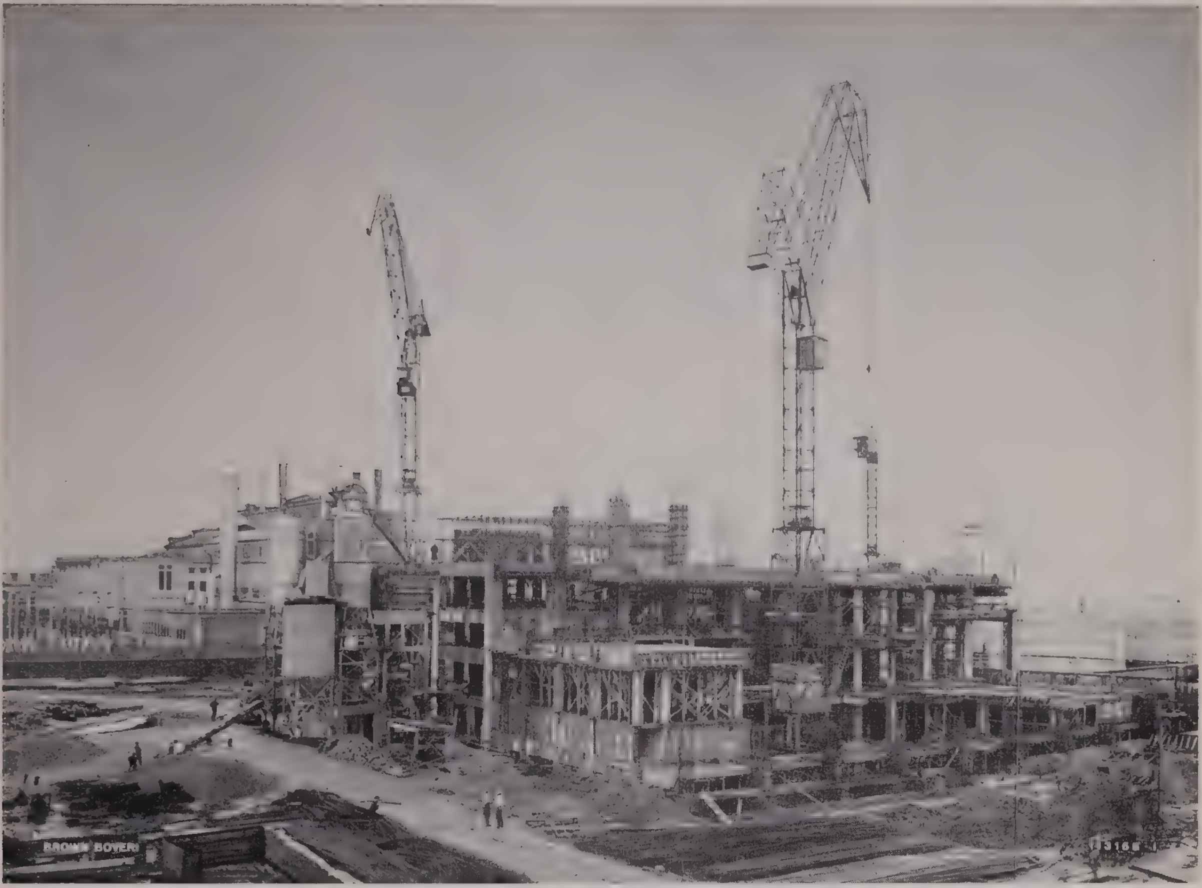


Fig. 14. – The site of the new steam power station of the Società Elettrica Selt-Valdarno, Leghorn, Italy

Recognizable near the site is the Luigi Orlando thermal power station where two 25-MW Brown Boveri gas turbines are installed.

between the foundation columns, and thereby achieves considerable economy in building. Continuous ejection of air is visualized in order to avoid the accumulation of air in the upper part of the water boxes. The condenser is spring supported and bolted direct to the turbine exhaust casing.

A *multi-shell, high-pressure feedwater heater* was built for the same installation at Amer power station. With this new kind of feedwater heater, operation of the plant is extremely flexible owing to the very low thermal stresses associated with this design. These items of equipment are built for pressures up to 450 kg/cm² (442 bar) on the water side. A simple cover closure provides access to the tube joints, so that checking is a simple matter when overhauls are carried out. The feedwater heaters with their steam elements are arranged vertically; this also enables the steam side of the exchanger to be readily inspected, simply by raising the steam shell (Fig. 16).

Cupro-nickel alloy of the type 80/20 was employed as tube material, so that tube corrosion problems will not arise even if starting and stopping becomes frequent later. In accordance with the Company's excellent experience, the tubes are expanded into the tube plates. It is only necessary to secure the tubes by welding when super-critical live-steam pressures are involved and when booster pumps are not employed.

From the sphere of *pressure-charged steam generators*, mention is made of the commissioning of the Velox steam generator for 32 t/h, 46 kg/cm² (45 bar), 460 °C, installed in the district heating station of the Basle City Electricity Authority. This represents a continuation of the development of the earlier design with respect to the ever-increasing live-steam figures.[3]

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[3] See L. GRECO: A new Brown Boveri Velox boiler in a municipal district-heating plant. Brown Boveri Rev. 1959, Vol. 46, No. 7, p. 371–80.

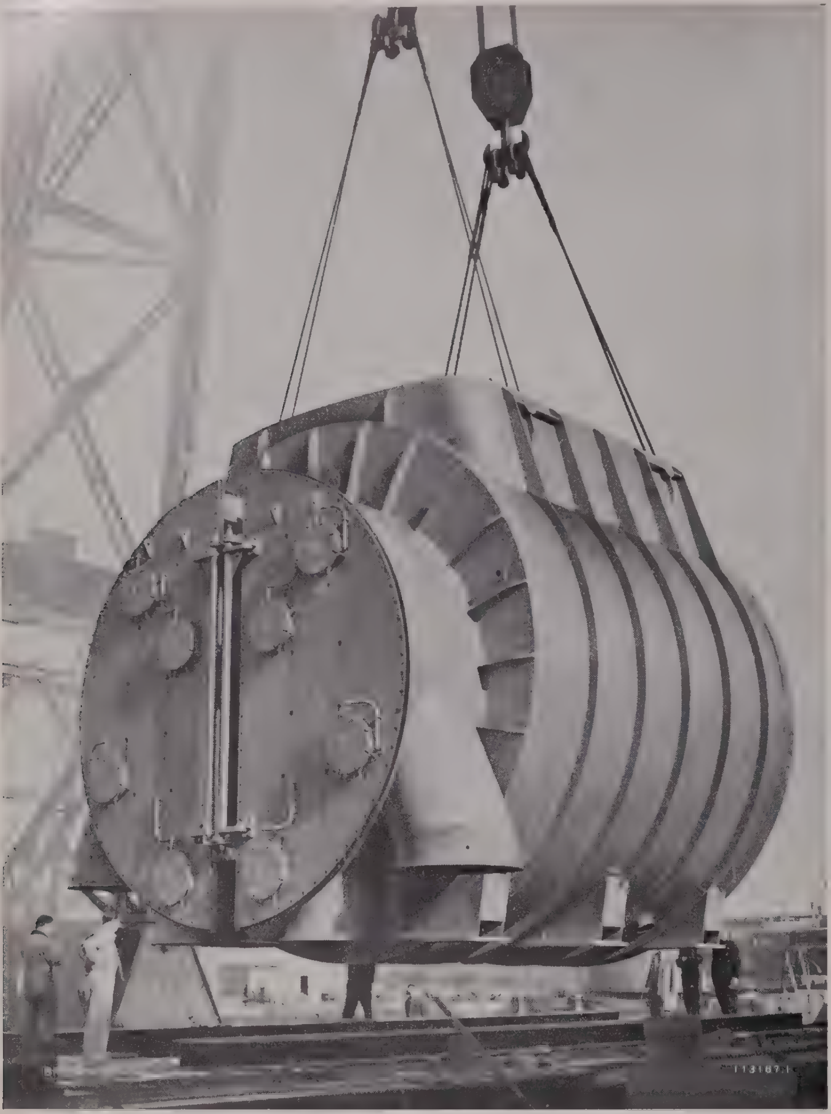

Fig. 15. – Surface condenser for a 150/175-MW steam turboset in the Amer power station owned by PNEM, Holland

This condenser contains 17 200 tubes 7 m long, with a total surface area of 9000 m².

The working cycle combining gas turbine and steam turbine offers new possibilities for the pressure-charged steam generator.

Nowadays when most electricity supply systems are extensively linked, the amount of surplus electricity which can be economically utilized in *electric steam generators* is steadily decreasing. Hence special applications tend to dominate. An example of this nature is offered by the inauguration of a 10 MW h.v. electric steam-raising unit for supplying saturated steam at 15 kg/cm² (14·7 bar). The generator, belonging to a steam turboset in a district heating station, is also occasionally run as a phase advancer, without uncoupling the turbine. During this type of operation the saturated steam from the electric steam-raising unit cools the steam turbine. Finally, its heat content is transferred in the condenser to the heating system.

3. Gas Turbines

During the years 1959 and 1960 the number of gas turbines put into industrial operation reached a peak, namely 38 sets with unit ratings ranging from 4 to 30 MW, or a total installed power of 536 MW.

Up to the end of 1960 the Brown Boveri concern had supplied 91 gas turbines. These units are to be found in almost all the parts of the world: Europe 37, Middle East 17, rest of Asia 3, North Africa 6, North America 17, and South America 11.

To these "classical" gas turbines the following sets may be added:

- about 110 charging sets for Velox boilers,
- about 30 charging sets for the Houdry cracking process,
- 27 hot-gas expansion turbines in connection with other chemical processes (manufacture of nitric acid, etc.),
- 10 expansion turbines connected to free piston gasifiers of the Pescara-Seme-Sigma system.

The Port Mann power plant near Vancouver in Canada is of special interest. The four units can be automatically started up, synchronized, loaded and shut down from the load despatching centre in Vancouver 25 km away.[4]

Another milestone was set with the erection of the Manama gas-turbine power plant in Bahrain. There, for the first time, a large public power system completely independent from other sources of energy is fed by gas turbines only.[5]

The first development stage of the Riyadh power plant erected in Saudi Arabia has been completed with its 4 out of 6 gas-turbine sets of the single-shaft type, with a terminal output of 6 MW. Some pictures of this power station showing different construction phases appeared in the last review of progress.[6]

This power plant was erected practically entirely by the Company; not only the turbosets were supplied by us, but also the rest of the mechanical and electrical equipment, including the materials for the building, the fuel tanks, the water tower, and so on. We were also entrusted with the general layout of the plant, as well as the supervision of the building work. It is also interesting to mention that a large part of the electrical transmission and distribution system in Riyadh and particularly in the royal palace compound was designed, supplied and erected by a Brown Boveri company (Brown, Boveri & Cie. AG., Mannheim). There cannot be many places where our material is so widely represented as in the capital city of Saudi Arabia.

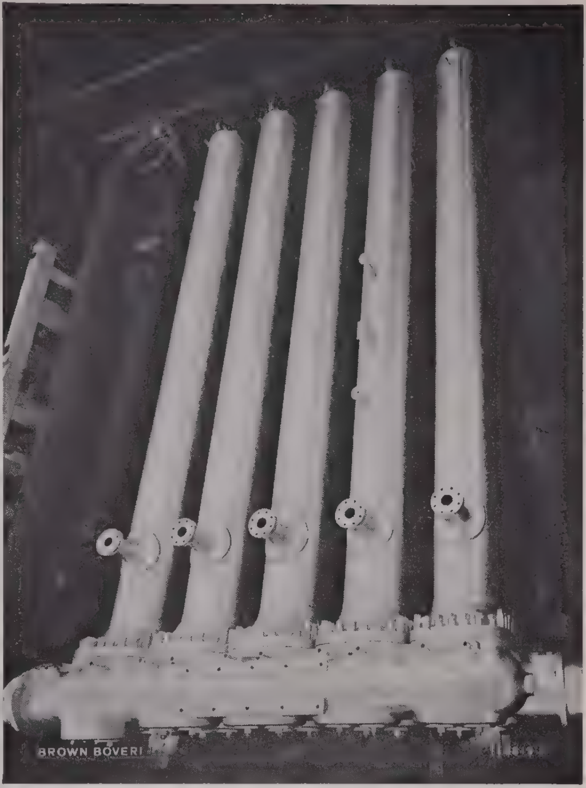

Fig. 16. – Condensate section of a high-pressure multi-shell preheater at the Amer power station of PNEM in Holland

The erection of the building for the first West African gas-turbine power plant at Afam near Port Harcourt, East Nigeria, was started recently (colour plates II and III). It is characteristic that gas tur-

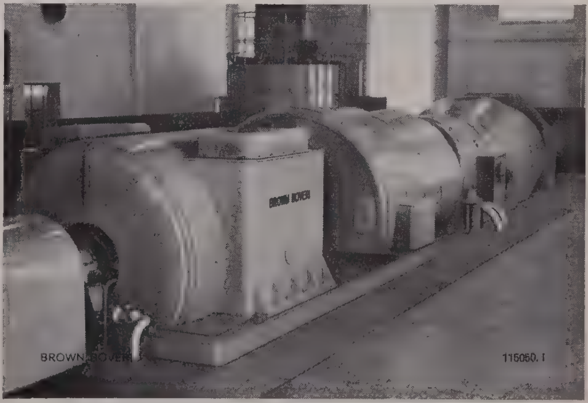

Fig. 17. – Gas-turbine power station of the Public Service Department, City of Moorhead, Minnesota USA

10-MW gas turboset for peak-load and emergency generation. Fuel: natural gas. This is the largest gas turbine set yet to be installed on the mainland of the USA.

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[4] R. Schmied: The world's largest gas-turbine power station, Port Mann in Canada. Brown Boveri Rev. 1960, Vol. 47, No. 1/2, p. 67–72.

[5] See also W. P. Auer: Manama gas-turbine power station—Bahrain. Brown Boveri Rev. 1960, Vol. 47, No. 1/2, p. 65/66.

[6] Brown Boveri Rev. 1959, Vol. 46, No. 1/2, p. 24/25.

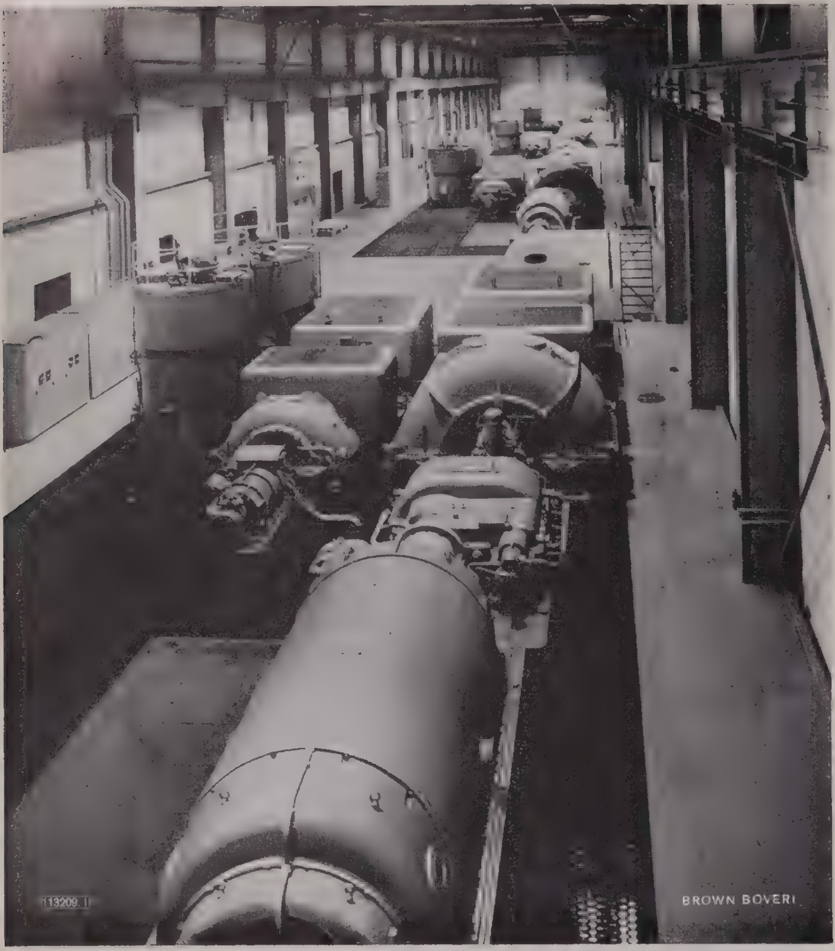

Fig. 18. – The gas-turbine power station Port Mann owned by the British Columbia Electric Company, Vancouver, Canada

With its four 27/30-MW gas-turbine sets this plant is the world's largest gas-turbine power station.

bines were chosen for this power station, situated in such a remote district and, at the same time, in a country which is only just beginning to develop.

More and more clients are asking for models when their power plants are being designed. The object of this is to obtain at an early stage a clear picture of the future appearance of the plant, as well as to ensure the most economical layout of all its components. A typical case is illustrated by colour plates IV and V. This new power station is located in the north-eastern part of Colombia, near the Venezuelan border, practically in the middle of the jungle. It has been planned for five 6000-kW gas turbine sets. Brown Boveri, in addition to supplying the turbosets, are to provide the rest of the mechanical and electrical equipment of the power plant, as well as the substations in the load centres fed by it.

Brown Boveri gas turbines are built for continuous operation and long life. Some of them have reached a yearly utilization factor of more than 97 %, thus proving their high reliability. Many machines have already respectable numbers of running hours to their credit (Table I). For instance, the 5400-kW set of the Dudelange steel works has completed more than 63 000 running hours (Fig. 19 and 20).

Some gas turbines have less running hours but a considerable number of starts. A gas turbine which has been running in Caracas since February 1958, for instance, has been started by remote control more than 800 times.

The utilization of the heat contained in the exhaust gases to increase the overall efficiency of a power plant is gained in importance.[7] In this respect an inter-

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[7] See also C. Seippel, R. Bereuter: The theory of combined steam and gas turbine installations. Brown Boveri Rev. 1960, Vol. 47, No. 12, p. 783–99.

W. P. Auer: Practical examples of utilizing the waste heat of gas turbines in combined installations. Brown Boveri Rev. 1960, Vol. 47, No. 12, p. 800–25.

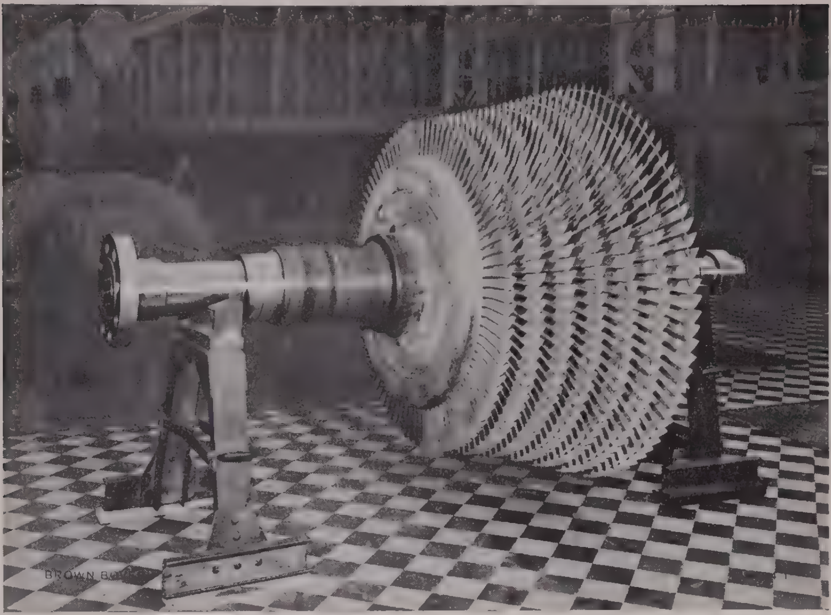

Fig. 19. – Rotor of the 5400-kW gas turbine in the Dudelange steel works of ARBED, after running more than 63000 hours

esting solution has been reached in the Vahr thermal power plant of the Stadtwerke Bremen.[8] The gas turbines in this plant were commissioned in 1959/60. Difficulties in obtaining cooling water, the limit of 2000 hours service per year and the desire to have an energy reserve always quickly available for peak load periods led to the choice of two gas-turbine sets of the well-proven 25-MW twin-shaft design. The heat taken from the turbosets for the district heating system is obtained partly from the compressor intercoolers, and partly from waste-heat boilers following the two turbines (total output of 26 MW per gas turbine). As this power plant is located near a residential area, special attention was devoted to soundproofing. The building, housing the machines and exhaust-gas heat recuperators has thick walls and no windows. The air inlet and the gas exhaust systems were provided with very effective silencers. In con-

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[8] See second article in footnote [7].

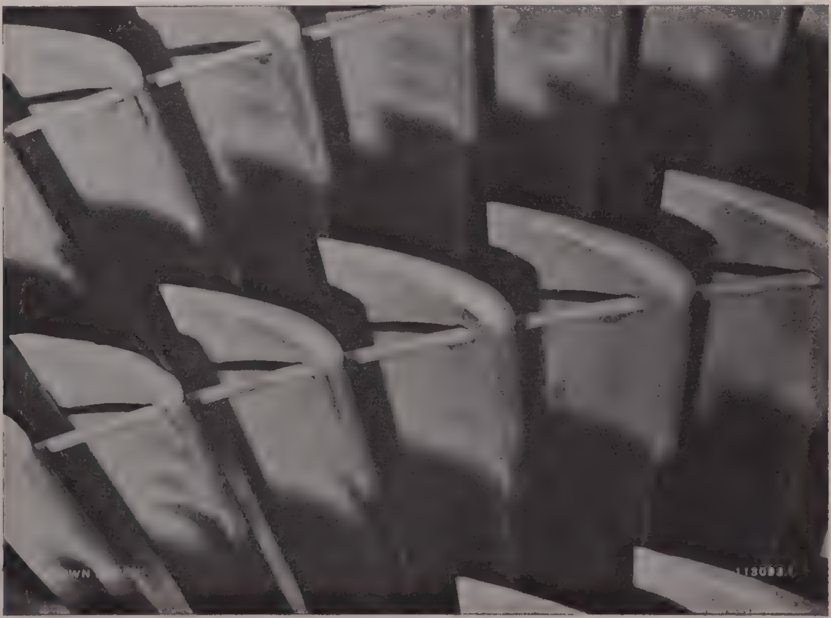

Fig. 20. – Close-up of the rotor blading of the 5400-kW gas turbine in the Dudelange steel works of ARBED after running more than 63000 hours

Notice the excellent condition of the rotor blading after such a long running period.

TABLE I

Performance of Brown Boveri gas-turbine installations

Installation	Commissioned	Rating kW	Running hours	Total output		No. of starts	Remarks
				MWh	up to		
Dudelange, Luxembourg	March 1951	5400	63278	330954	29.11.60	—	90% electricity 10% cold blast
Pertigalete III, Venezuela	January 1953	5000	53003	190678	30.12.60	82	Base-load unit
Pertigalete IV, Venezuela	April 1955	5000	40915	149646	30.12.60	72	Base-load unit
El Convento, Venezuela	February 1958	20000	2971	54010	31.12.60	893	Peak-load unit
Dhahran II, Saudi Arabia	April 1954	5000	42703	177560	31.12.60	224	Base and peak-load unit
Kindersley I, Canada	January 1958	10000	12222	78908	31.10.60	610	Base-load unit
Lethbridge, Canada	February 1958	6000	11461	62506	17. 9.60	798	Peak-load unit
Vermilion, Canada	October 1954	6000	16607	87036	31.10.60	1377	Peak-load unit
Edmonton, Canada	November 1958	30000	4831	114975	31.10.60	480	Peak-load unit
St. Dizier, France	August 1956	6000	2854	15649	15.10.60	834	Peak-load unit 750° type
Sta. Cruz I, Algeria	October 1957	12000	4362	34551	30.11.60	842	Peak-load unit
Sta. Cruz II, Algeria	November 1957	12000	3799	32417	30.11.60	756	Peak-load unit
Haspe, Germany	July 1958	14000	17645	229805	25.12.60	9*	Base-load; 750° type ⅔ electricity ⅓ cold blast

* Including commissioning

nection with the noise level guarantees, measurements were made in spring of 1960 on the first turboset and very satisfactory results obtained; this proves that with a certain amount of additional expenditure it would be quite possible to install gas-turbine plants in residential areas. The noise level at different points of the premises boundary was never more than 50 DIN-Phon (Fig. 21).

The first combination of large gas-turbines with a steam-turbine process has been achieved in the thermal power station of the Niederösterreichische Elektrizitätswerke AG. and the Verbundgesellschaft in Korneuburg, Austria. A waste-heat boiler with auxiliary firing (built by Wagner-Biró, Graz) is connected to each of the two normal 25/30-MW double-shaft gas-turbine sets. The two boilers together produce 100 t/h of steam at 15·5 kg/cm² and 450 °C, which is used in a steam turboset to produce 25 MW at the terminals.

A very thorough description of the Brown Boveri gas-turbines built for an inlet temperature of 750 °C, and a detailed analysis of the problems arising in connection with them can be found in a recent issue of the Brown Boveri Review.[9]

The use of the gas turbine in connection with the Pescara free-piston gasifier system is increasing (Fig. 22 and 23).

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[9] H. PFENNINGER: Brown Boveri gas turbines for an inlet temperature of 750 °C. Brown Boveri Rev. 1960, Vol. 47, No. 1/2, p. 35–64.

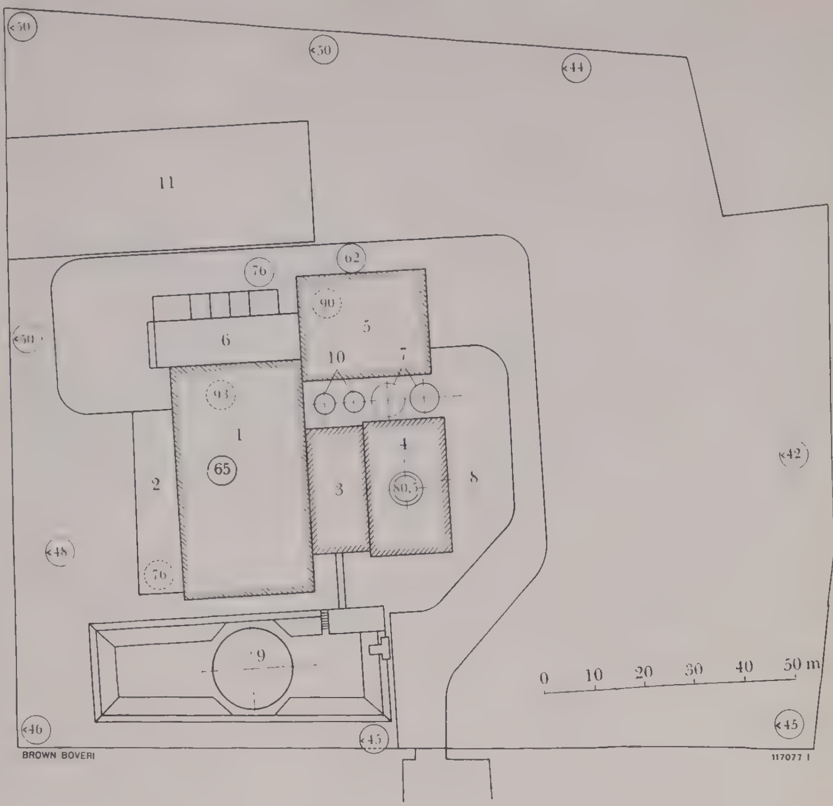

Fig. 21. – Vahr gas-turbine power station near Bremen, with two 25-MW twin-shaft gas-turbine sets

General layout plan showing noise level values in DIN-Phon, measured according to DIN 5045, at the different points of the installation.

1 = Machine room
2 = Air inlet
3 = Control room
4 = Waste-heat boiler room
5 = Boiler room
6 = Switchgear room
7 = Hot-water reservoir
8 = Exhaust stack
9 = Main fuel-oil tank
10 = Fuel-oil tank
11 = Switchyard
(50) = Outdoor noise level
(76) = Indoor noise level

The employment of the free-piston system for marine propulsion is worth mentioning. The two new Dutch banana freighters "Geestland" and "Geestar" have completed their trials and have been finally taken over. Four free-piston units, manufactured by Werkspoor, produce the driving gases (4·1 kg/cm^2, 450 °C) which are expanded in a Brown Boveri gas turbine giving 4000 hp at 5500 rev/min. By using a variable-pitch propeller, a special gas-turbine section for reversing can be dispensed with.

4. *Nuclear Power Stations*

In the field of peaceful uses of atomic energy the considerable efforts which have been made have resulted in only partial success for the Company. This is mainly due to the world-wide restraint which has marked business in this field in recent years. As long as nuclear power stations with their particularly high investment costs are uneconomical in comparison with conventional steam power stations—a state of affairs which will probably continue for the next few years—the number of nuclear power stations, mostly built with government support, will remain small and free competition will be restricted by protectionist trends and by a complicated system of national and international agreements of a technical and financial nature.

Nevertheless, we may report with some satisfaction that the joint development of a high-temperature gas-cooled reactor, carried out by Brown, Boveri & Cie. AG., Mannheim, and Friedrich Krupp, Essen, has resulted in an order for a 15-MW prototype with the full accompanying power station. With a gas-outlet temperature of 850 °C, the highest conceived so far, with the pebble-bed design for spherical fuel elements using graphite without metallic canning, and with the uranium-thorium fuel cycle, promising high conversion ratios, this first prototype German power reactor represents a well-advanced design.[10] For this project Brown Boveri, Baden, Switzerland, undertook the development of the coolant circu-

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[10] R. SCHULTEN and E. JANTSCH: The Brown Boveri–Krupp high-temperature gas-cooled reactor. Brown Boveri Rev. 1960, Vol. 47, No. 1/2, p. 88–96.

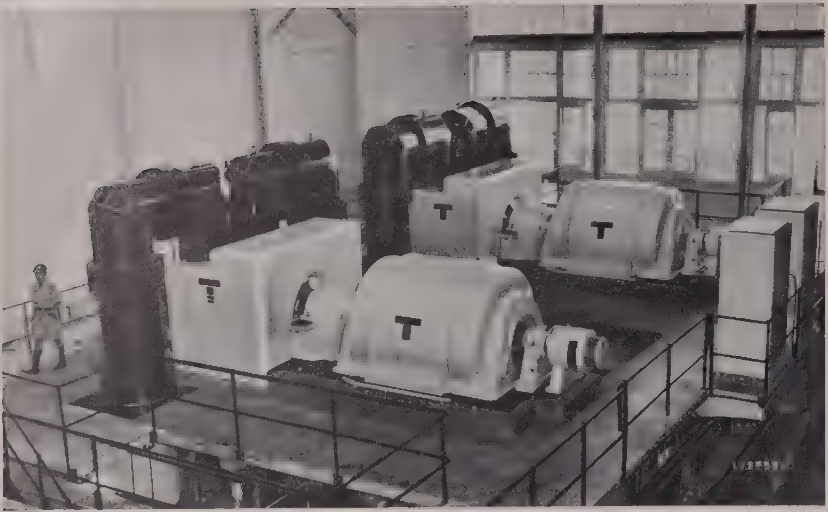

Fig. 22. – The 36-MW power station in Singapore

Turbine house with two of the six 6-MW expansion turbines connected to free-piston gasifiers. On the left are the turbines and gas pipes; on the right, the generators and exciters. (Material supplied by Cie Electro-Mécanique, Paris.)

lators which have to comply with strict specifications, in view of the radioactively contaminated coolant gas and the necessity of avoiding any lubrication oil leakage whatsoever into the coolant loop.

The French member of the concern, the Compagnie Electro-Mécanique, Paris, belongs to the "Indatom" group formed by a number of French firms and is participating in the development of the heavy-water moderated and CO_2 gas-cooled natural uranium reactor EL–4 and its 100-MW power station (start of construction planned for 1961). Another project initiated by the French Atomic Energy Commission, and at present in the development stage, concerns the nuclear propulsion unit for a tanker, using a gas-

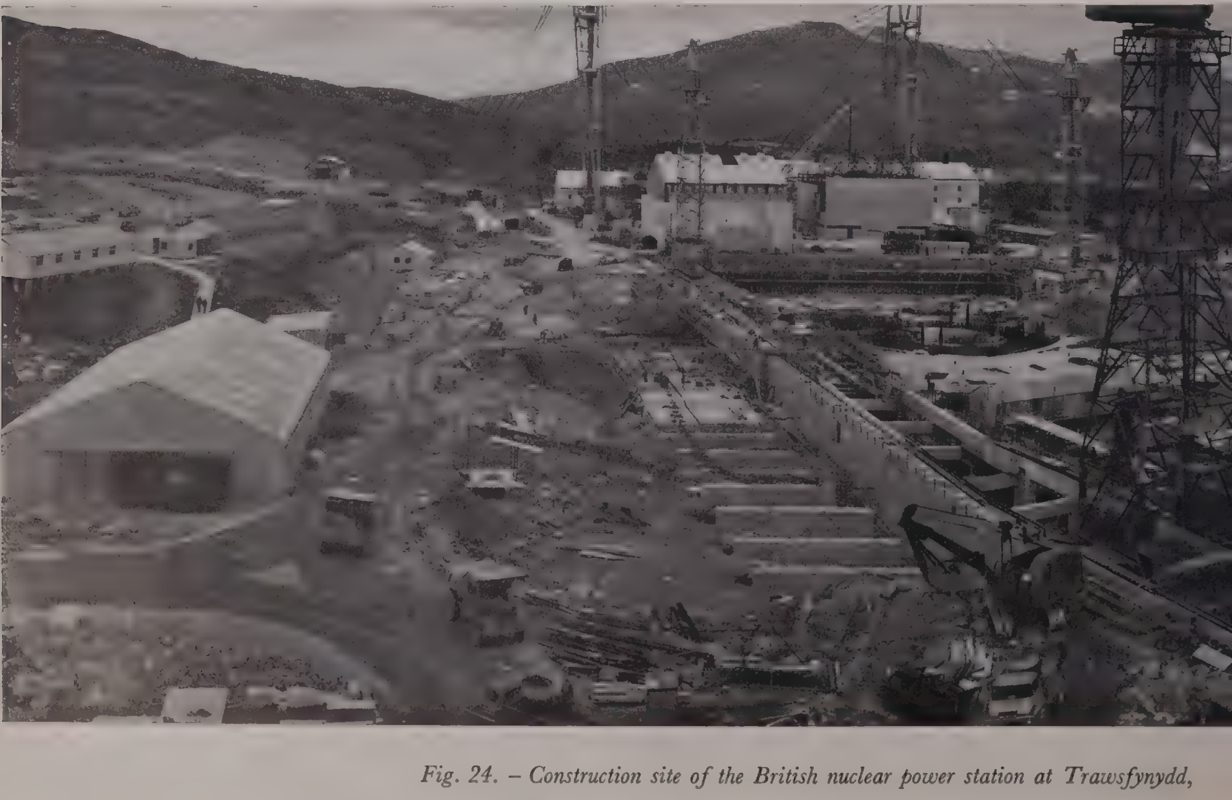

Fig. 24. – Construction site of the British nuclear power station at Trawsfynydd,

In the centre, the inner shell of the concrete shielding round one of the two

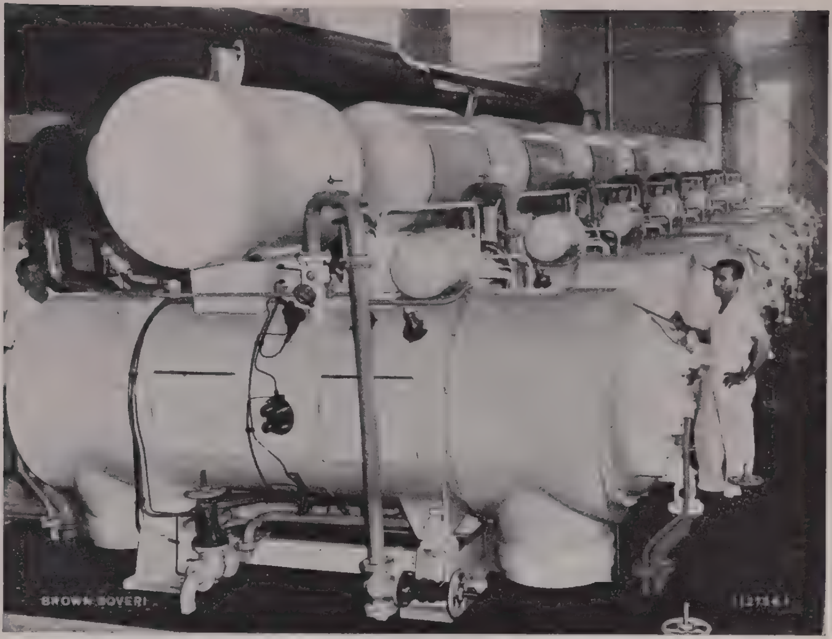

Fig. 23. – The 36-MW power station in Singapore

A group of eight free-piston gasifiers made by the Free-Piston Engine Co., Feltham, England, supply the driving gases for a 6-MW expansion turbine.

cooled reactor. The Compagnie Electro-Mécanique also supplied some of the equipment for the "hot" laboratory of the national nuclear research centre at Saclay near Paris.

A particularly valuable order received by Richardsons Westgarth as a member firm of the Atomic Power Constructions Ltd. (APC), includes four 145-MW turbosets of Brown Boveri design for the Trawsfynydd

which will be equipped with four 145-MW turbosets of Brown Boveri design

reactors is already erected; at the rear are the foundations for the turbine house.

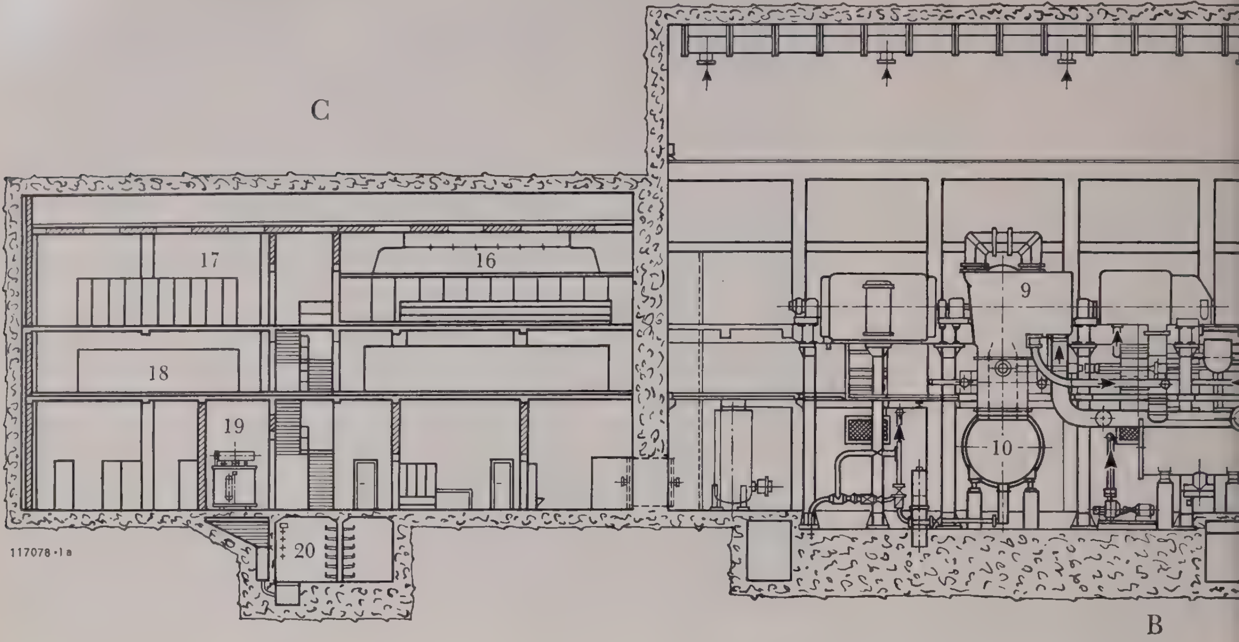

Fig. 25. – Elevation of the caverns of the "Aare" nuclear power station project, using a direct-cycle boiling-water reactor

A. Reactor cavern

1 = Reactor
2 = Pressure-tight reactor "dry well"
3 = Steam vent pipes (in case of a primary system rupture)
4 = Cold-water pool for steam condensation after primary system rupture
5 = Feed pumps for reactor core spray system (in case of loss of coolant)
6 = Pressure-tight air-lock
7 = Pressure-tight intermediate chamber for steam and feed-water pipe bushings
8 = Pressure-tight air-lock with fuel-element transport car

B. Machinery cavern

9 = Turbo-alternator
10 = Condenser
11 = Air ejectors with jet water basin
12 = Feedwater tank with deaeration
13 = Feedwater pumps
14 = Transport car for spent fuel elements (transport to the outside through the tunnel perpendicular to figure)
15 = Air cooling and recirculation system

C. Control cavern

16 = Control room
17 = Switchgear
18 = Cable cells
19 = Transformer
20 = Piping and cable channel to outside (together with personnel tunnel)

nuclear power station[11] [12] (Fig. 24). In particular for this order and in general for the saturated steam or low superheat steam turbines that are in demand for most of the present reactor systems, extended series of experiments have been conducted in Baden to develop efficient systems for removing moisture. A combination of different external scrubber arrangements satisfies the requirements at acceptable pressure losses.

In addition to our own reactor development, concentrated at Brown Boveri, Mannheim, the concern continued to follow the same basic principle of open and world-wide co-operation with manufacturers of various types of reactor, as has hitherto been observed with respect to conventional boiler manu-

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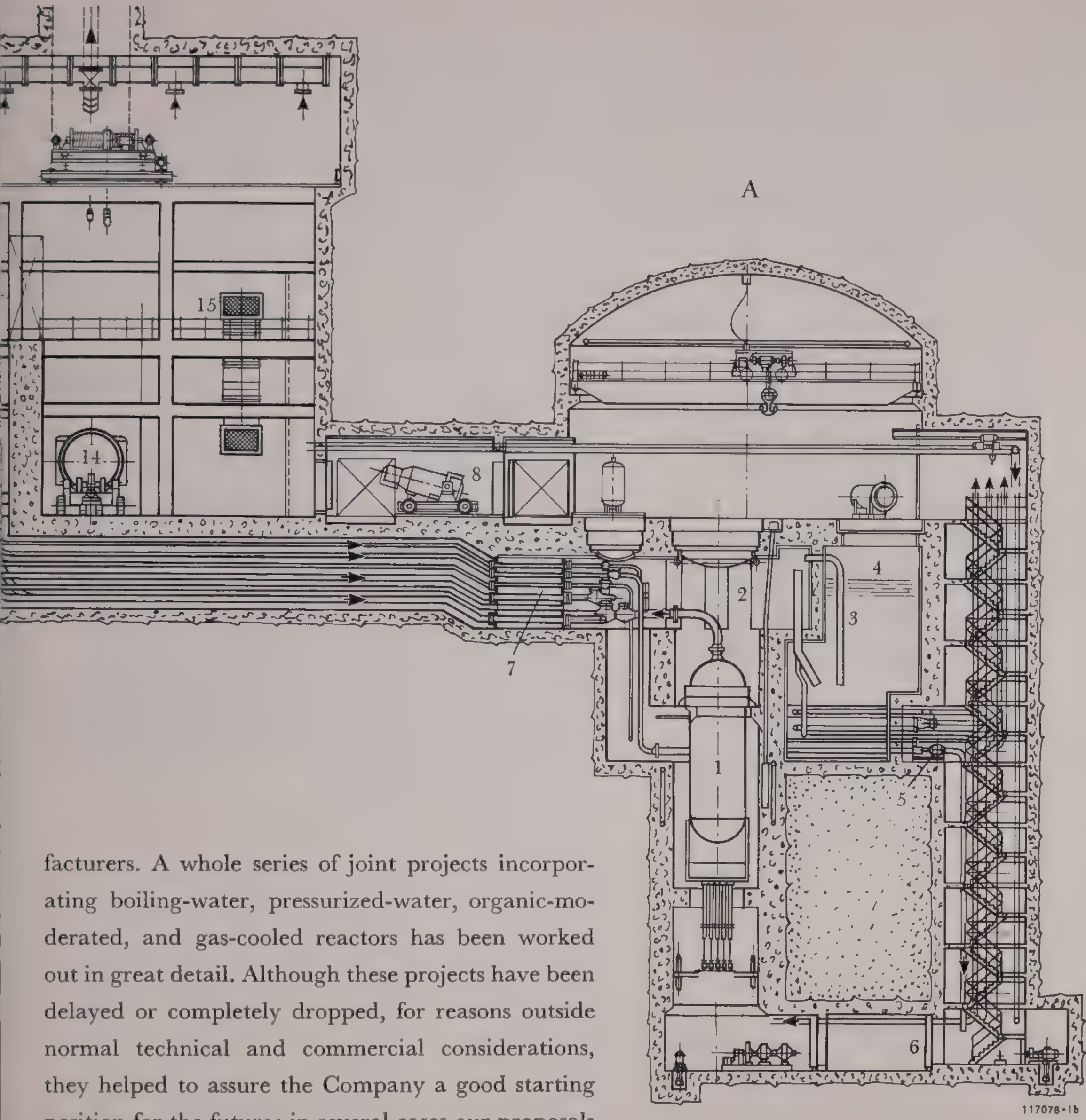
[11] E. A. KEREZ: Trawsfynydd Atomic Power Station in North Wales. Brown Boveri Rev. 1959, Vol. 46, No. 7, p. 381–4.

[12] E. JANTSCH: The Trawsfynydd Nuclear Power Station from the technical point of view. Brown Boveri Rev. 1960, Vol. 47, No. 1/2, p. 97–106.



facturers. A whole series of joint projects incorporating boiling-water, pressurized-water, organic-moderated, and gas-cooled reactors has been worked out in great detail. Although these projects have been delayed or completely dropped, for reasons outside normal technical and commercial considerations, they helped to assure the Company a good starting position for the future; in several cases our proposals were chosen as the best in spite of the usual fierce competition in this field.

The Swiss "Aare" project, planned for Suisatom by Brown Boveri, Baden, in collaboration with the General Electric, USA, the North East Swiss Power Co., Electro-Watt, and Brown Boveri, Mannheim, is particularly interesting because of the underground installation (Fig. 25) with three safety barriers in series between reactor and environs: a cold-water pool around the reactor with forced steam condensation in case of a primary system rupture, a pressure-tight air-lock between the reactor chamber and machinery chamber, and a pressure-tight air-lock in the access tunnel. For this power station with an output of 17·3 MW (later to be raised to 27·4 MW), using an advanced boiling-water reactor with direct steam flow to the turbine, the design work progressed to maturity and furnished most valuable experience with the wide variety of new problems encountered in planning nuclear power stations with all their complicated auxiliary circuits, including treatment and disposal of radioactive waste. The development of a safety concept, however, that satisfies the rigorous standards of protection against the consequences of every possible kind of accident even more onvincingly than has been usual so far in countries hich indemnity protection is guaranteed by the government, will guide future designs of nuclear power stations in densely populated areas and has also won international recognition.

Another proposal, jointly worked out by Brown Boveri and Babcock & Wilcox, USA, for the 170-MW nuclear power station originally planned by S.E.P. (N. V. Samenwerkende Electriciteits-Productiebedrijven, Arnhem, Netherlands) as part of the Euratom programme, is also founded on this basic principle of maximum safety. The pressurized-water reactor with the entire primary system is enclosed in a pressure-tight spherical steel containment above ground, which in turn is enclosed by thick concrete shielding. This arrangement not only ensures adequate radiation shielding in the postulated case of a primary system rupture, but affords the additional possibility of extracting any possible radioactive leakage through the steel containment and, after mechanical and chemical filtering, of diluting and discharging it through the high chimney (Fig. 26); thus all danger is avoided even in the immediate vicinity of the reactor building.

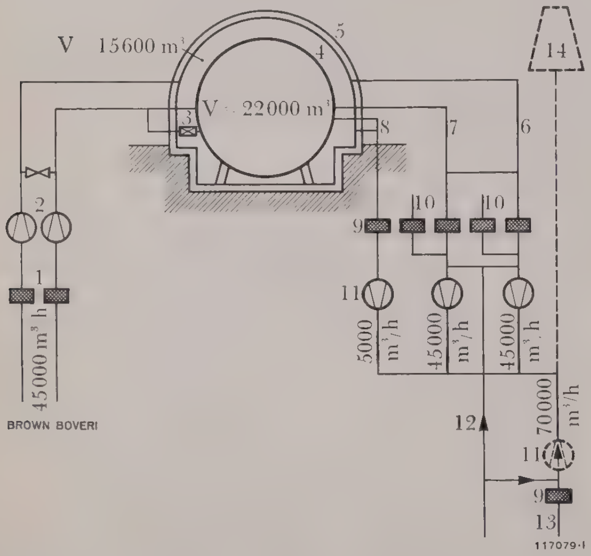


Fig. 26. – Ventilation flow diagram of the reactor building for the S.E.P. (Netherlands) nuclear power station project

During reactor operation the air is cooled and recirculated inside the containment.

1 = Air intake filters
2 = Air intake blowers
3 = Pressure control for containment
4 = Containment (steel sphere)
5 = Outer concrete shielding
6 = Air extraction from space between sphere and concrete shielding, for large flow
7 = Air extraction from containment, for large flow (scavenging air)
8 = Air extraction for small flow
9 = Air discharge filter
10 = Air intake for dilution
11 = Air discharge blowers
12 = Exhaust gases from primary systems
13 = Exhaust gases from auxiliary buildings
14 = Chimney

In collaboration with the Atomics International Co., USA, and their German licencee Interatom, projects have been developed with organic-moderated reactors (for example AKS, Stuttgart), and in collaboration with the Nuclear Power Plant Company (NPPC), England, with gas-cooled reactors.

In the summer of 1960 the "Diorit" heavy-water research reactor of the Swiss Federal Institute of Reactor Research at Würenlingen was put into operation without any difficulties or incident. This is a remarkable success for the team that had studied, designed, and constructed this reactor, first in our firm, and later in the larger frame of Reactor Ltd. For the "Diorit" Brown Boveri supplied two heavy-water circulation pumps with glandless motors (see page 85), the complete control rod drives for coarse and fine control (Fig. 27), and a special heat exchanger. For test purposes we designed and built an electromagnetic liquid sodium pump.

B. Electrical Equipment for Power Stations

1. Turbo-alternators

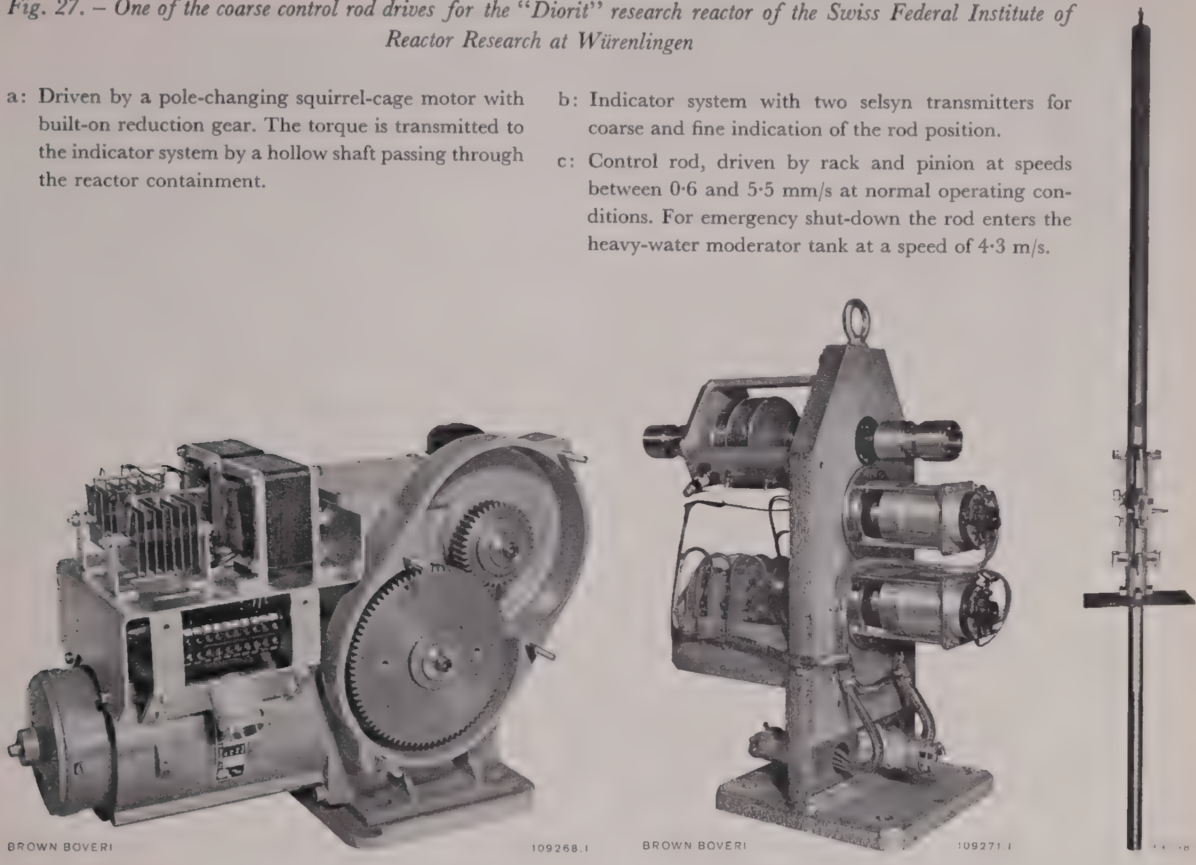
The unit outputs of alternators, in particular turbo-alternators, continue to grow as the demand for electricity increases. But since there are limits to the growth of the volume of such alternators, for technical reasons, the utilization factor (power per unit volume) must be raised. For the most part this is merely a question of losses. On the one hand great efforts are required to reduce the losses, in

Fig. 27. – One of the coarse control rod drives for the "Diorit" research reactor of the Swiss Federal Institute of Reactor Research at Würenlingen

a: Driven by a pole-changing squirrel-cage motor with built-on reduction gear. The torque is transmitted to the indicator system by a hollow shaft passing through the reactor containment.

b: Indicator system with two selsyn transmitters for coarse and fine indication of the rod position.

c: Control rod, driven by rack and pinion at speeds between 0·6 and 5·5 mm/s at normal operating conditions. For emergency shut-down the rod enters the heavy-water moderator tank at a speed of 4·3 m/s.



a b c

order that increasing utilization may not adversely affect the efficiency; on the other hand the residual heat, which increases with the utilization, must be dissipated at the given, permissible temperatures. The result of limiting the temperature is that all heat drops must be eliminated from the flow of heat, from the point at which it is produced to the coolant. This is the basic idea behind *direct cooling*.

The first step in this direction was the introduction of direct cooling of the rotor conductors, the direct contact between the copper and the cooling gas being achieved by making the conductors hollow and allowing the gas to flow through them. Thus there arose the well-known design with directly-cooled rotor and conventionally-cooled stator. Next the capacity of the stator had to be matched to the increased capacity of the rotor. This led to direct cooling of the copper in the stator winding. In this case Brown Boveri proceeded straight to liquid cooling, allowing oil or water to flow through the hollow stator conductors. Fig. 28 shows a sectional view of an alternator of this kind. This machine is for the Trawsfynydd atomic power station, for which four units rated 170·5 MVA, 3000 rev/min, power factor 0·85, are at present being built under licence by Richardsons Westgarth in Hartlepool. In these machines the stator winding is water-cooled. Colour plate VI shows the end-coils with the oil inlet hoses for the stator of the alternator rated 164 MVA, 3000 rev/min, power factor 0·8, for Harculo power station of the N.V. Electriciteitsfabriek IJsselcentrale, Zwolle, Holland, while being erected on the test-bed of Brown Boveri, Mannheim. The same principle was adopted for two alternators rated 270 MVA, power factor 0·85, for 3600 rev/min, at present being built in Baden for the Department of Water and Power of the city of Los Angeles, USA. Likewise, our associate company in Italy, Tecnomasio Italiano Brown Boveri,

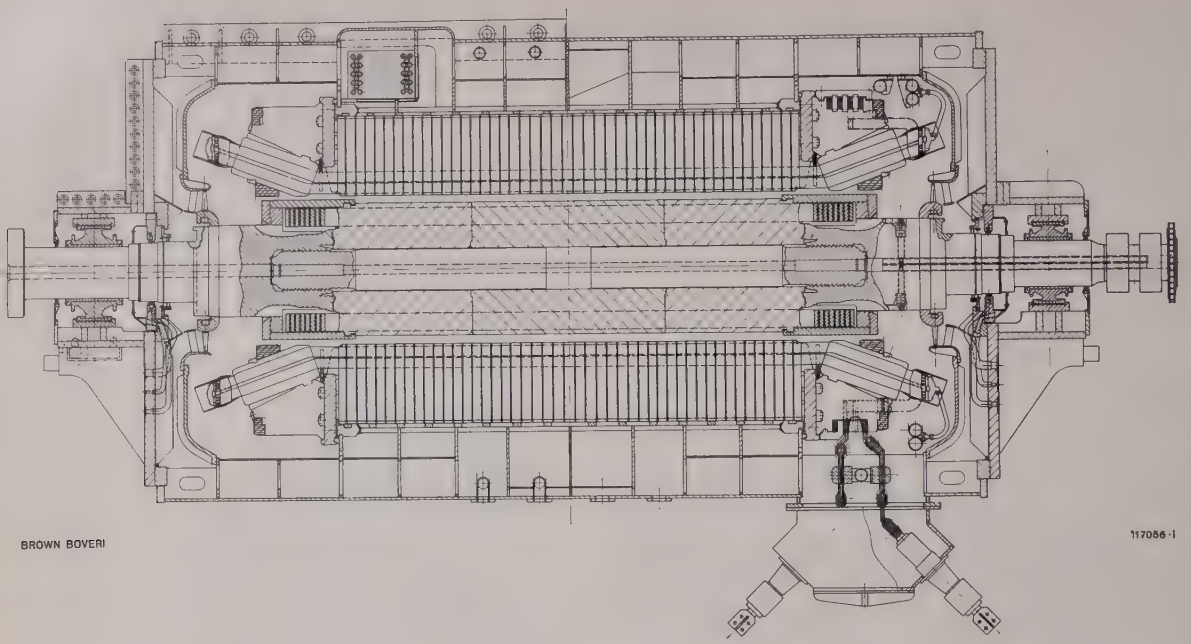


Fig. 28. – Sectional elevation of a turbo-alternator rated 170·5 MVA, 3000 rev/min, p.f. 0·85, being built for Trawsfynydd atomic power station in Wales

The conductors of the rotor winding are cooled direct with hydrogen, those of the stator winding with water.

Milan, have an alternator on hand for an output of 206 MVA at 3000 rev/min, power factor 0·8.

As a result of its winding being liquid-cooled, the stator is now at an advantage over the rotor as regards its output capacity. For increasing the capacity of the rotor there are now two possible approaches. Either the static gas pressure may be increased, so that more gas flows through the conductors, but this results in heavy windage losses at the rotor surface. Alternatively the gas throughput can be increased, while keeping to the same static pressure, by utilizing a compressor, the pressure of which is added to the static pressure of the rotor. In the latter case the ventilation losses increase. Obviously an optimum compromise must be found by combining the static gas pressure and the supplementary pressure of the compressor. Fig. 29 shows the curve of the ventilation and windage losses in a generator for a definite temperature rise, in function of the static gas pressure. The sum of the two losses passes through a minimum; this value should be adhered to as closely as possible when designing the machine. The two points plotted denote the optimum gas pressure and the value actually obtained, respectively.

Naturally the gas pressure selected must be adapted to the arrangement of the rotor winding. The closest match is obtained by calculating several variants and approaching by trial and error. Electronic computers can render great service here, as they are able to calculate a large number of variants in a very short time. It is possible to calculate the temperature rise of individual hollow conductors in terms of their length, from which the mean temperature rise of the winding is determined. At the moment two generators with forced rotor cooling and liquid stator cooling are being built in Baden. They are rated 305·555 MVA, 3600 rev/min, power factor 0·9, and are for delivery to the Tennessee Valley Authority, USA. Fig. 30 shows a sectional elevation of one of these machines. A notable feature is the pair of radial fans connected in series with the rotor circuit. The principle of direct cooling is also employed for the stator iron in these machines, finely distributed axial channels in the laminations being provided, through which the hydrogen can flow to carry the heat away almost from the point at which it is generated. In this way the usual temperature drops at right-angles to the stacks of laminations are avoided.

The final step towards intensifying the stator cooling for machines for extremely high outputs was taken in the alternator for the Amer power station of PNEM in Holland, in which the stator iron and pressure plates are also oil-cooled, in addition to the stator winding. This alternator, designed as a prototype, was commissioned in the autumn of 1960. Fig. 31 shows the stator of this 260-MVA machine being erected prior to trials in the factory, while Fig. 32 shows it arriving at the station.

Now that various methods of improving the utilization are available, the output limits must be fixed on the basis of economic considerations, in order to decide within which limits a certain method should be employed. This is decided by the comparison between the savings effected in the cost of the machine by the improved utilization, and the capitalized extra cost arising out of the additional losses which accompany it. Fig. 33 gives a rough idea of the type allocation of Brown Boveri turbo-alternators

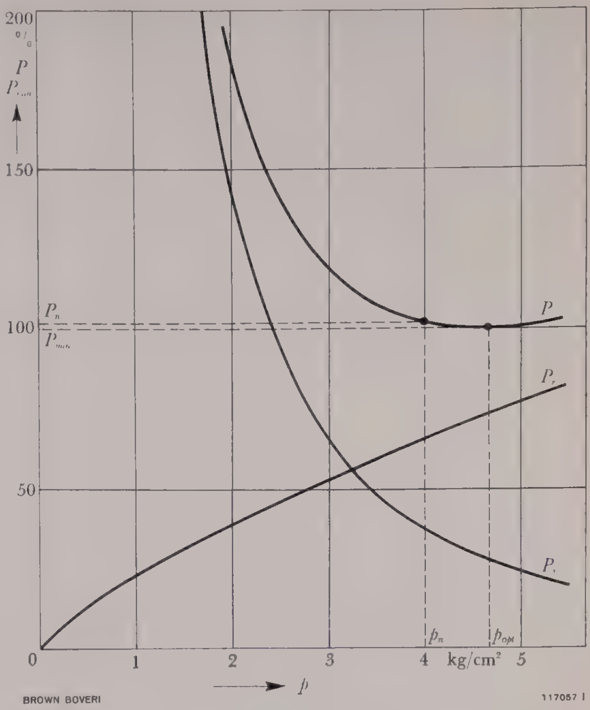


Fig. 29. – Ventilation and windage losses in a turbo-alternator for a definite temperature rise in the rotor, as a function of the static hydrogen pressure

P_r = Windage losses
P_v = Ventilation losses
P = Sum of windage and ventilation losses
p_{opt} = Optimum gas pressure for minimum losses
p_n = Rated pressure chosen for the machine

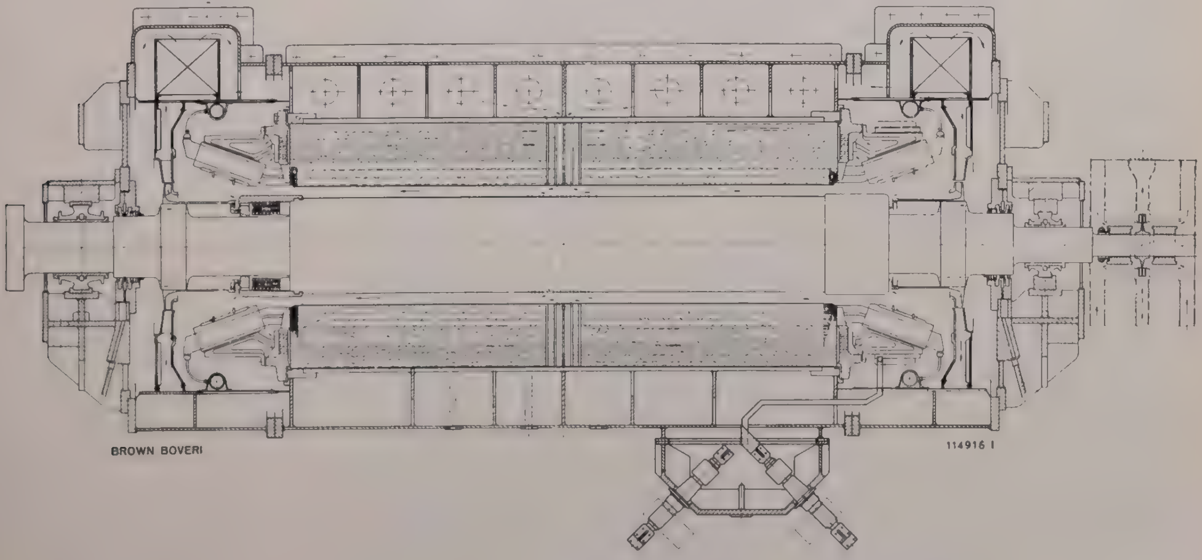


Fig. 30. – Section through a 305·555-MVA generator, 3600 rev/min, for the Tennessee Valley Authority

The two radial fans are connected in series with the rotor, in the gas stream. The stator laminations are cooled with hydrogen passing through finely distributed axial ducts. The stator winding is oil-cooled.

according to the system of cooling employed. The boundaries in this allocation are drawn sharply. In reality though the various methods overlap one another, depending on the assessment of the losses applicable in a specific case, as well as for reasons associated with uniformity of production.

Close attention is paid to the smooth running of alternators. Here too the electronic computer renders invaluable service during manufacture. The hollow conductors for the rotor are delivered with a certain tolerance, an unfavourable combination of which may lead to thermal unbalance in the slots. Therefore the conductors are individually measured on arrival in the works. From the measurements so obtained, the computer determines the most favourable combination for each slot and prescribes which conductor should be laid in which slot. In this way the differences between the temperature rises of individual slots can be kept at least one order of magnitude smaller than corresponds to the tolerances of the delivered conductor material. Thus the risk of thermal unbalance being caused by uneven temperature rise is practically eliminated.

The large alternators are, of course, insulated with Micadur. This new elastic, synthetic resin insulating material, which Brown Boveri employ for all

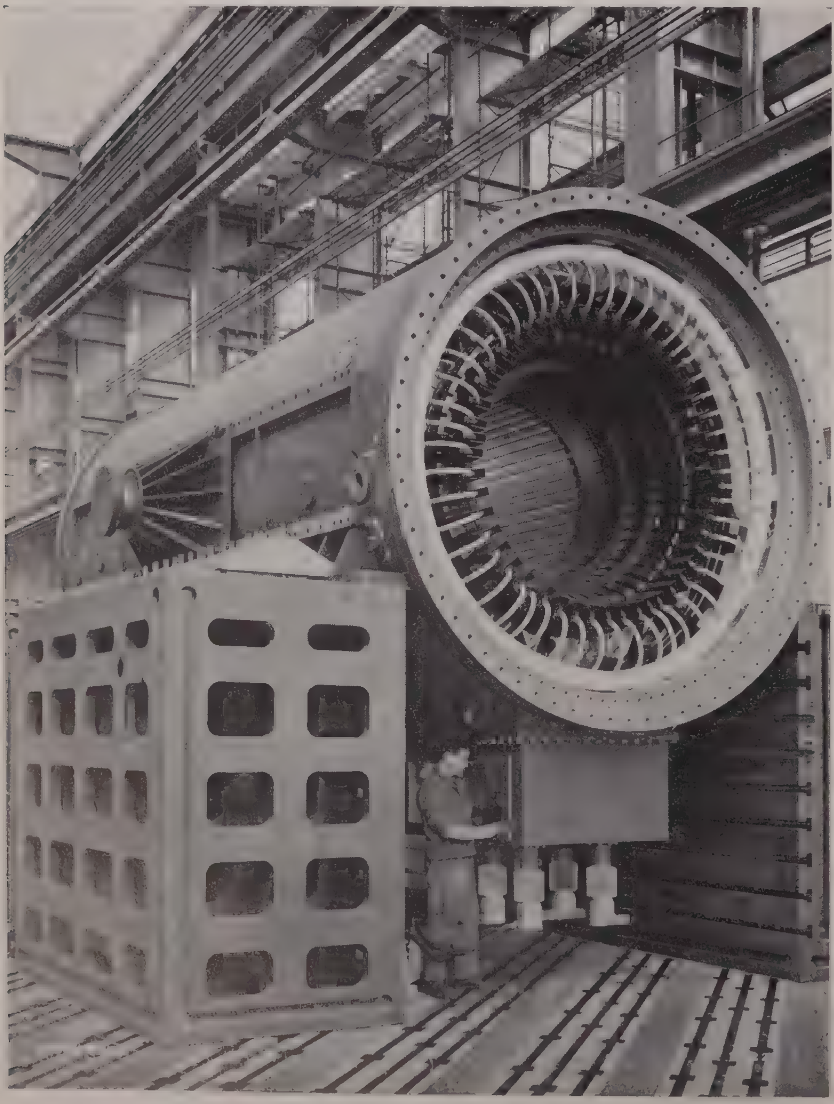


Fig. 31. – View of the stator of No. 5 generator at Amer power station in Holland, owned by PNEM

This generator, which has a rated output of 219 MVA, was built as prototype for the range of high-output alternators having a type rating of 260 MVA and over. In addition to the stator winding, the stator iron and pressure plates are also cooled with oil.

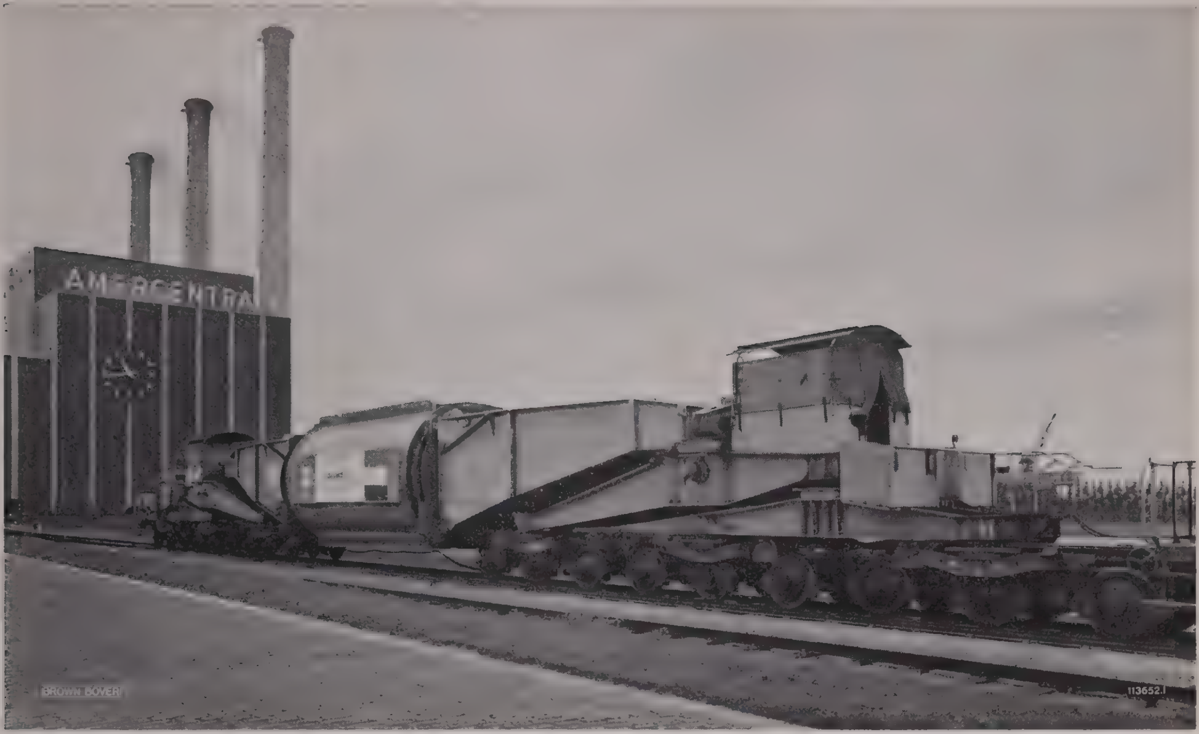


Fig. 32. – Showing the stator arriving at the power station

The weight carried by the well wagon on which it was transported amounted to about 170 t.

generators whose iron length exceeds 3·5 m, was fully described in an earlier issue of this Review and in a CIGRE report.[13, 14]

2. Hydro-Electric Generators

2.1 Horizontal alternators

For the horizontal alternators, driven by Pelton wheels at each end, the arrangement with which the exciter is situated outside the main machine set has become more or less standard practice. Fig. 34 shows a section through one of the four sets in Tavanasa power station of Kraftwerke Vorderrhein, Baden, each of which produces 60 MVA at a speed of 375 rev/min and a power factor of 0·7. The main and pilot exciters, and the permanent-magnet generator are accommodated in a common casing with two bearings and, in this particular case, connected to the main shaft through gear couplings; other forms of flexible coupling can also be employed. Compared with former arrangements, in which the main exciter was built into the generator, the latest arrangement offers certain advantages. The exciter can be a perfectly ordinary d.c. machine made of standardized parts and does not have to be designed as a large-diameter machine. This is beneficial as regards the commutation. In contrast to designs with built-in exciter, the commutator is easily accessible, especially with low shaft-centre heights. The pole-pieces of the alternator can also be withdrawn without hindrance by the exciter. The increase in the overall length of the set is insignificant, especially for small-diameter generators with a low number of poles. For overhauls the exciter set is easily dismantled and, if necessary, can be replaced quickly by a spare set. The turbine runner at the exciter end can be dismantled without

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[13] B. Doljak, M. Moravec, O. Wohlfahrt: Micadur, a new insulation for the stator windings of electrical machines. Brown Boveri Rev. 1960, Vol. 47, No. 5/6, p. 352–60.

[14] A. Ritter, O. Wohlfahrt: Dielectric measurements on the insulation of stator windings. CIGRE 1960, Report No. 122.

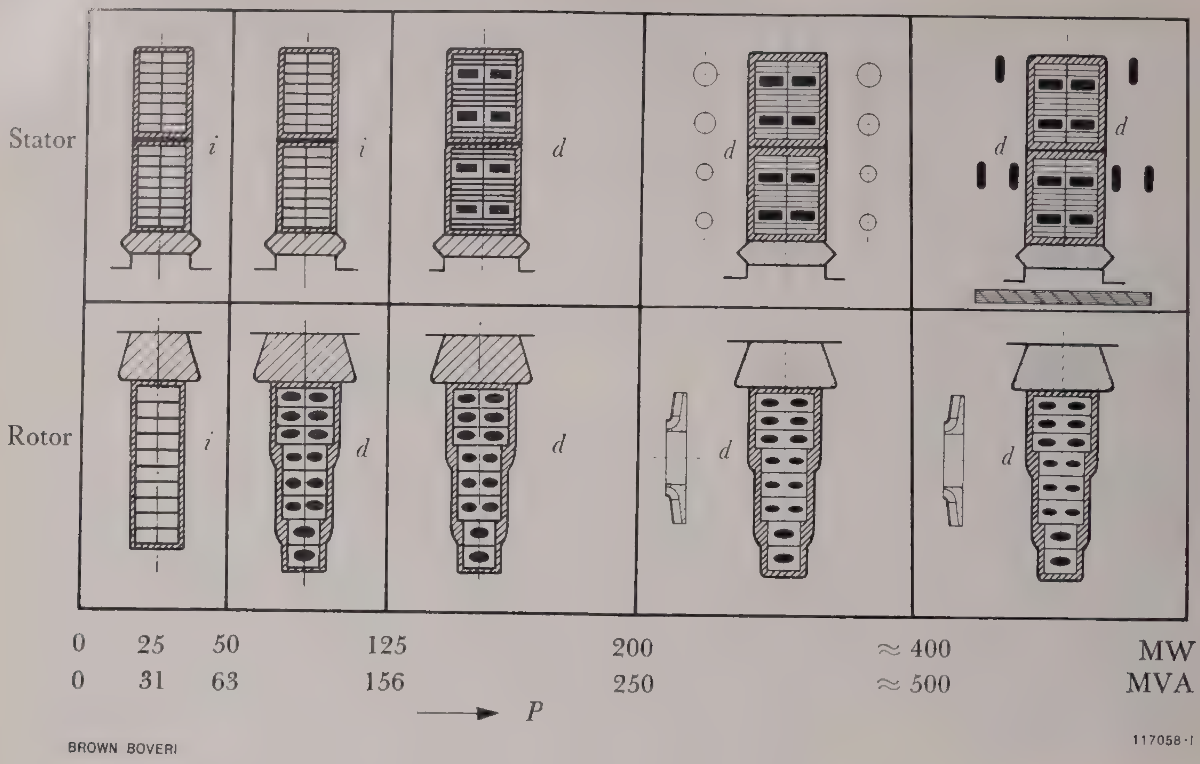

Fig. 33. – Allocation of the system of cooling to Brown Boveri turbo-alternator types

Stator	Air	H_2	H_2	Oil (water)	Oil (water)	Oil
Rotor	Air	H_2	H_2	H_2	H_2 with compressor	H_2 with compressor

i = Indirect cooling *d* = Direct cooling *P* = Alternator output in MW or MVA

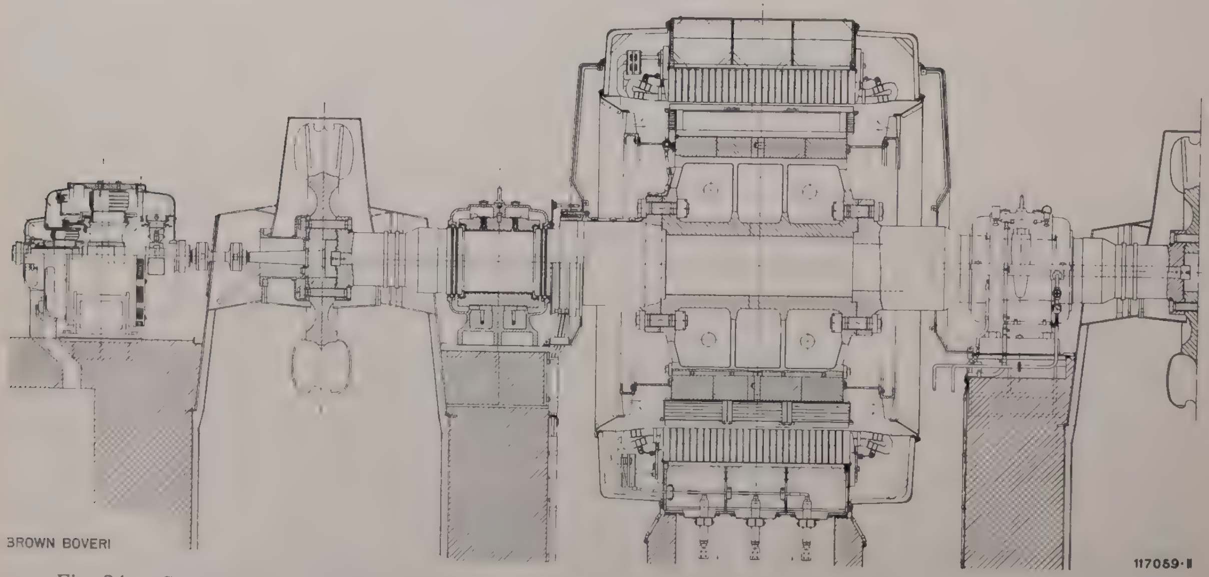

Fig. 34. – Section through a 60-MVA, 375-rev/min alternator for Tavanasa power station of Kraftwerke Vorderrhein

The main and pilot exciters and the permanent-magnet generator are combined to form a separate machine set, situated beyond the turbine runner and coupled through gear couplings to the main shaft.

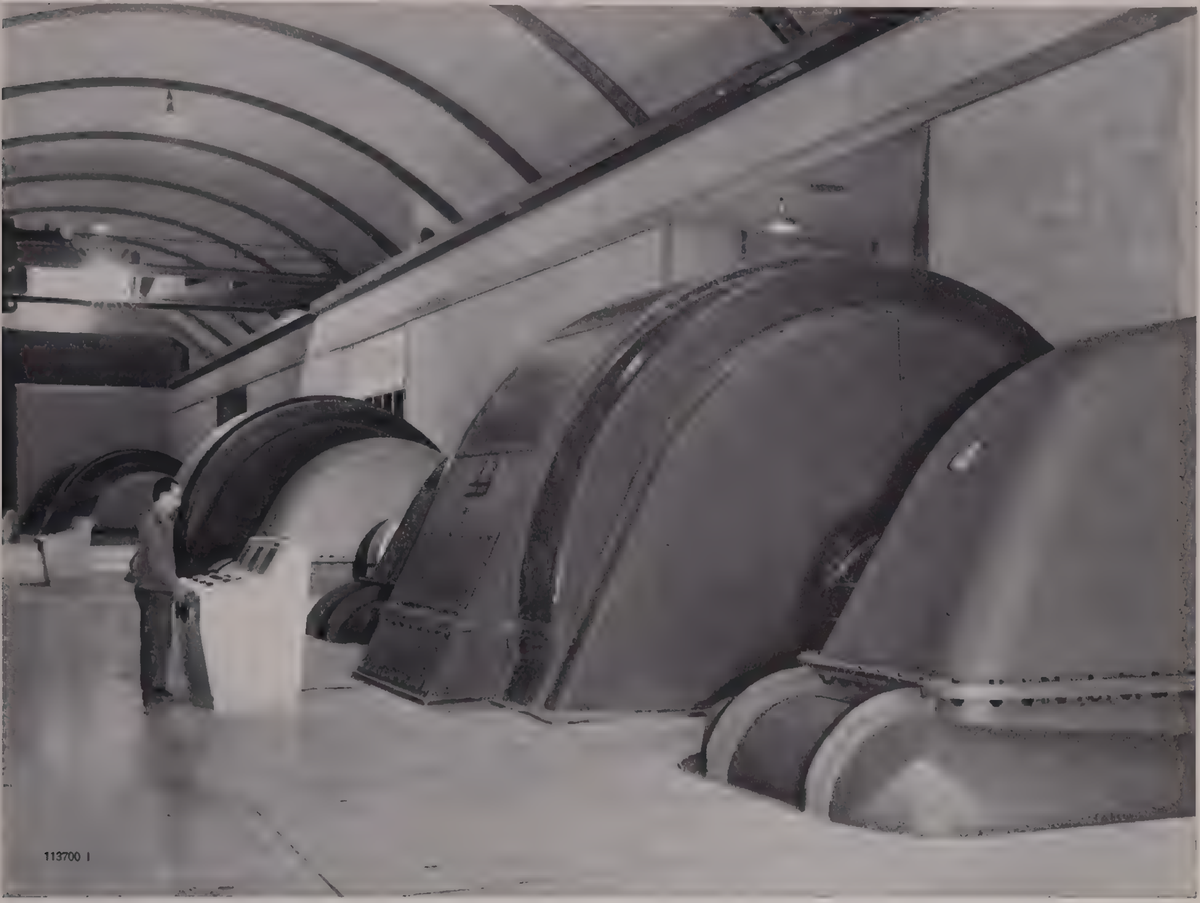

Fig. 35. – Machine hall of Biasca power station of the Blenio Power Co., Locarno, Switzerland, showing the four 80-MVA generators running at 333·3 rev/min, power factor 0·9

the exciter set having to be touched. The shaft section between the two gear couplings merely has to be removed, thus affording enough space for work on the turbine runner.

It may justifiably be claimed that Brown Boveri occupy a leading position in the construction of such generator sets; during the last two years no fewer than 15 sets have been delivered. Among these are the four 80-MVA alternators for 333·3 rev/min, p.f. 0·9, installed in Biasca power station of the Blenio AG. and taken into service last year (Fig. 35). Ten more generators are at present under construction in the works, including three rated 100 MVA, p.f. 0·8, for 600 rev/min, due to be delivered to Tierfehd station of the Linth-Limmern scheme and two generators rated 85 MVA at 514 rev/min for Huinco power station of Energía Hidro-Eléctrica Andina S.A. in Peru.

2.2 Vertical alternators

For vertical alternators driven by Pelton turbines it used to be customary to provide three bearings, the turbine having its own bearing so that it could withstand the thrust of the jet. Now that cooling coils are cast into the bearing shells to dissipate the heat directly, it is possible to provide self-lubricating vertical bearings capable of withstanding the heavy bearing forces. The arrangement with only two bearings, as depicted in Fig. 36, was chosen for the two alternators rated 53·3 MVA, p.f. 0·75, 500 rev/min, for Göschenen power station in Switzerland. Fig. 37 shows the stator of this gene-

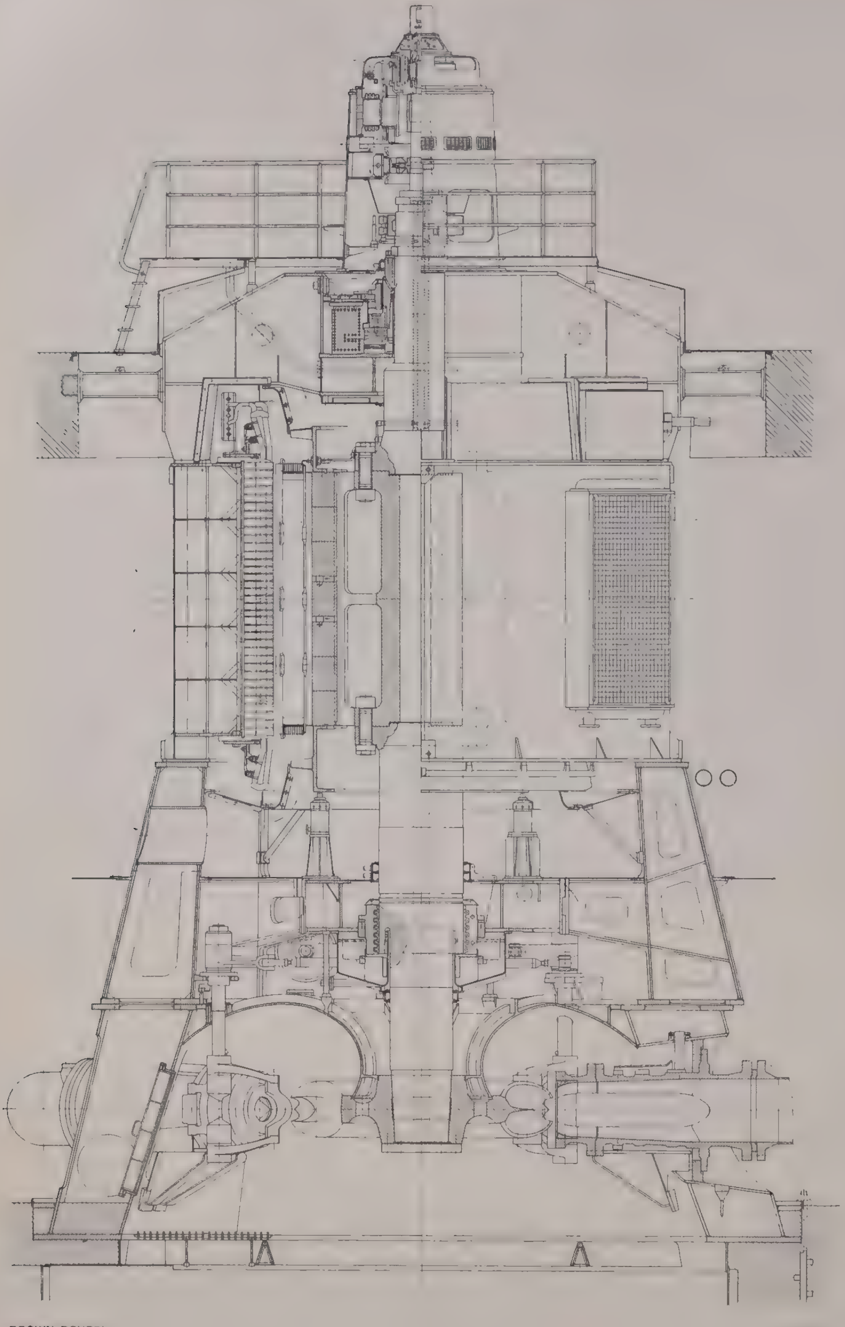

Fig. 36. – Section through a 53·3-MVA alternator for 50 c/s, 500 rev/min, built for p.f. 0·75, Göschenen power station, Switzerland

This machine set has only two guide bearings. The thrust of the Pelton jets is taken up by the lower bearing of the generator, which has cooling coils cast into the bearing shell.

rator in the factory, and Fig. 38 the rotor being lowered into position in the power station.

For the vertical, slow-running alternators the overhead (or "umbrella") system continues to gain in popularity. Below the rotor of the alternator is the combined thrust and guide bearing; there is no further bearing above the rotor. With this design the bearings are made accessible either from above or below. Fig. 39, which shows a section through one of two generators of this design, rated 18 MVA each at 71·5 rev/min, p.f. 0·7, ordered for the Schaffhausen power station on the Rhine, illustrates the arrangement with thrust bearings accessible from above. For overhaul the rotor spider is supported on

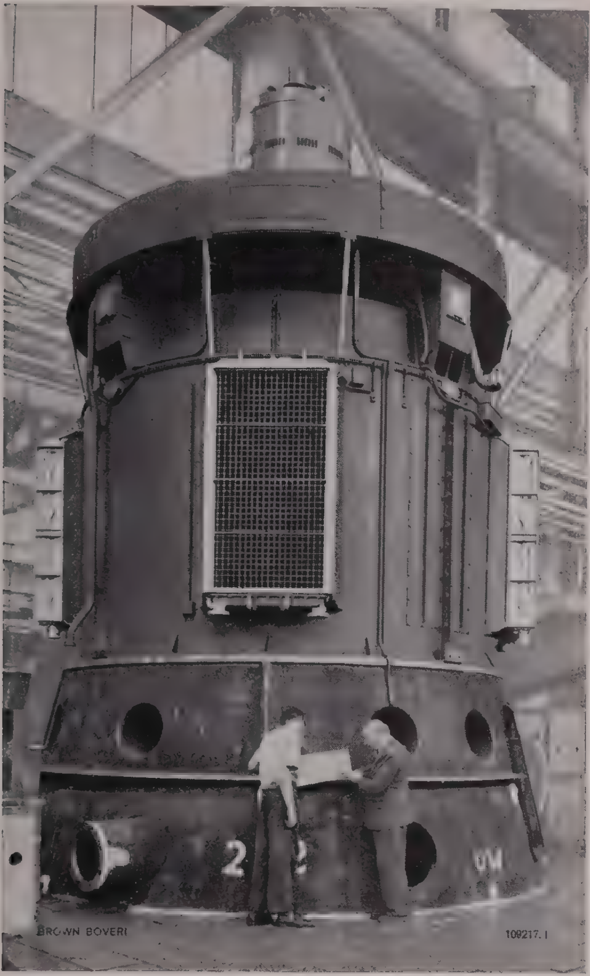

Fig. 37. – View of the stator of the machine in Fig. 36 during mechanical assembly in the factory

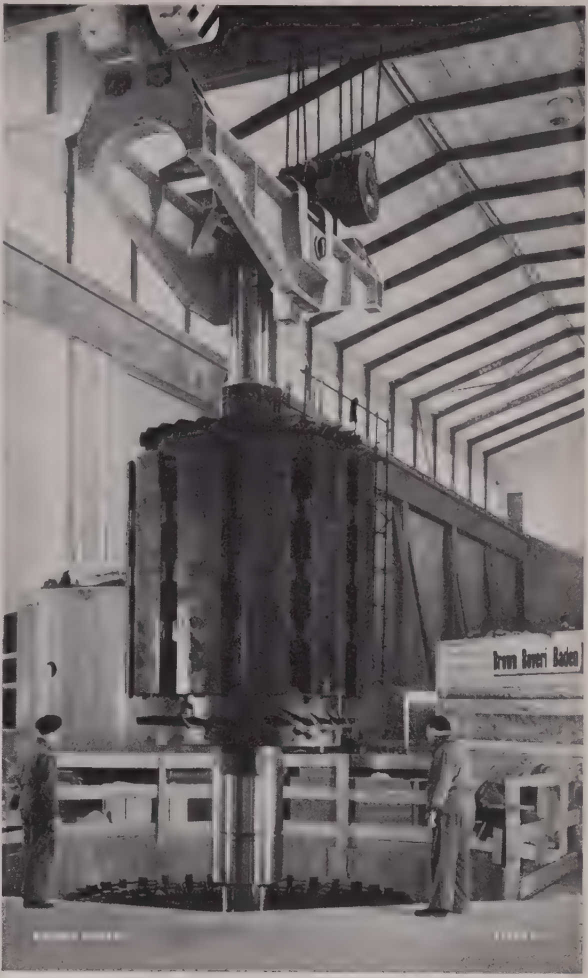

Fig. 38. – Inserting the rotor into the stator of the machine at Göschenen power station

the jacks and the supporting head removed upwards. This exposes the combined thrust and guide bearing. The superstructure of this generator is particularly low because the main and pilot exciters are arranged as a separate machine set fed by the built-on shaft-driven generator. The bearing can be inspected from below by lowering the thrust bearing. A design of this kind is illustrated in Fig. 40. This is a section through one of three alternators rated 60 MVA, 60 c/s, 106 rev/min, power factor 0·9, being built at present in the Baden and Mannheim works for Wilson Dam power plant of the Tennessee Valley Authority. The thrust bearing segments of these generators are supported on a ring which can be lowered by a special mechanism. To even out the distribution of the load, each segment can be adjusted for height individually. The guide bearing is also equipped with adjustable segments, thus permitting the realization of a very small radial clearance. These machines will be excited by built-on main and pilot exciters and controlled by high-power regulators type KC. Fig. 41 shows this alternator being assembled in the factory. Since this machine will be installed out of doors, it is enclosed by a strong, tightly closed casing, as can be seen in the sectional view.

In the last review of progress, published two years ago, mention was made, among the vertical alternators for very high outputs, of an order received for Tokke power station in Norway, covering four

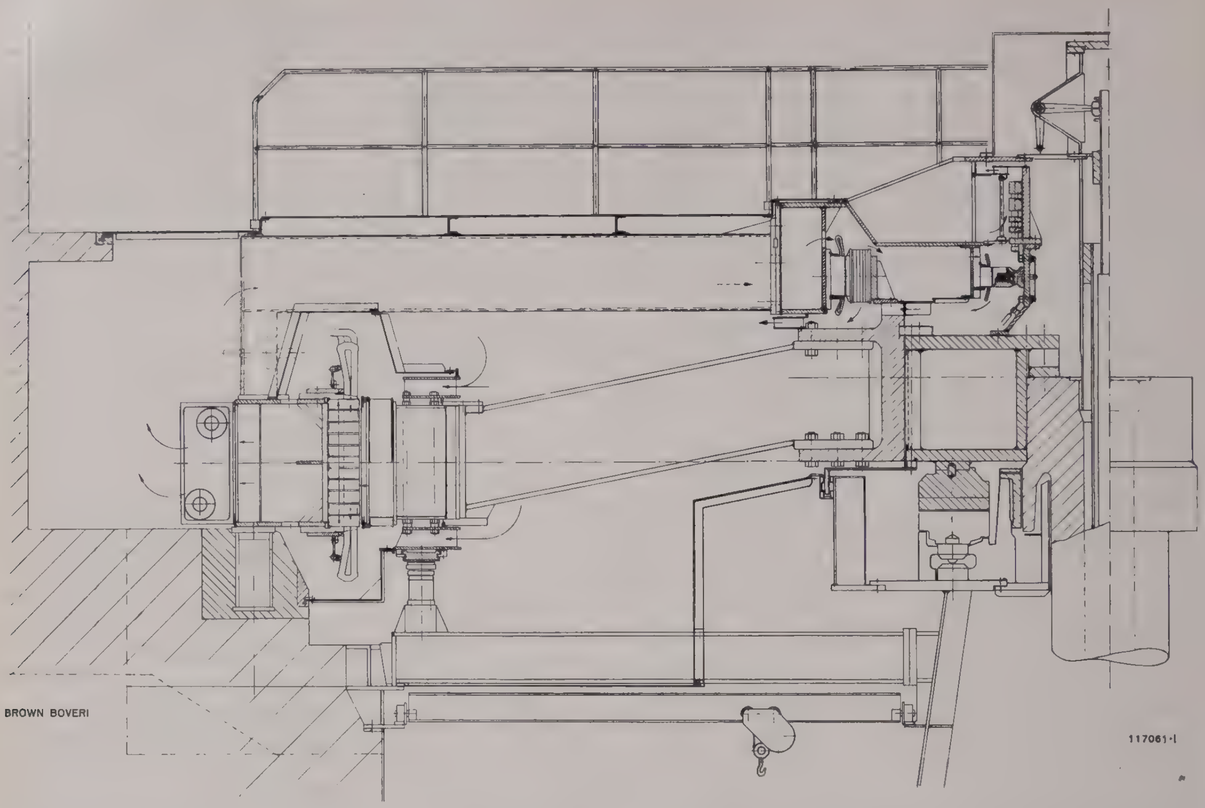

Fig. 39. – Section through an 18-MVA, 71·5-rev/min alternator for the Rhine power station of the Elektrizitätswerk Schaffhausen, Switzerland

After removing the thrust head, the thrust bearing is accessible from above for inspection.

generators rated 120 MVA, 375 rev/min, p.f. 0·8, placed by the Norwegian Hydro-Electric Board. These machines were built in Baden and in the Oslo works of Norsk Elektrisk & Brown Boveri, the first having already been delivered. Fig. 42 shows the stator being assembled in the factory.

The large generators also referred to two years ago for Grosio power station of AEM, Milan, have now been taken into service (Fig. 43). They are vertical alternators rated 115 MVA at 333 rev/min, each of which is driven by a four-jet Pelton turbine. These alternators were built in Milan by Tecnomasio Italiano Brown Boveri. They have the largest unit output of any hydro-electric alternators operating in Italy. With their 115 MVA they are indeed ahead of all vertical alternators driven by Pelton turbines. The generator itself weighs 600 t, of which the rotor alone accounts for 300 t. The voltage is regulated by the newly developed Brown Boveri transistorized controller.

2.3 D.C. generators

As part of a scheme for modernizing and extending their plant, the firm of Elektrochemie Turgi, Switzerland, demolished an old part of the Schiffmühle generating station belonging to the factory and, in its place, extended a newer section by adding two new d.c. generators driven by Kaplan turbines and producing an output of 1125 kW each at 225 V and 95 rev/min (Fig. 44). The generators stand on the machine-house floor, their fans drawing in air from the basement and expelling it upwards into the machine room. Round their upper periphery they are fitted with detachable windows, through which the commutator and brushes can be inspected, and the latter renewed, if necessary.

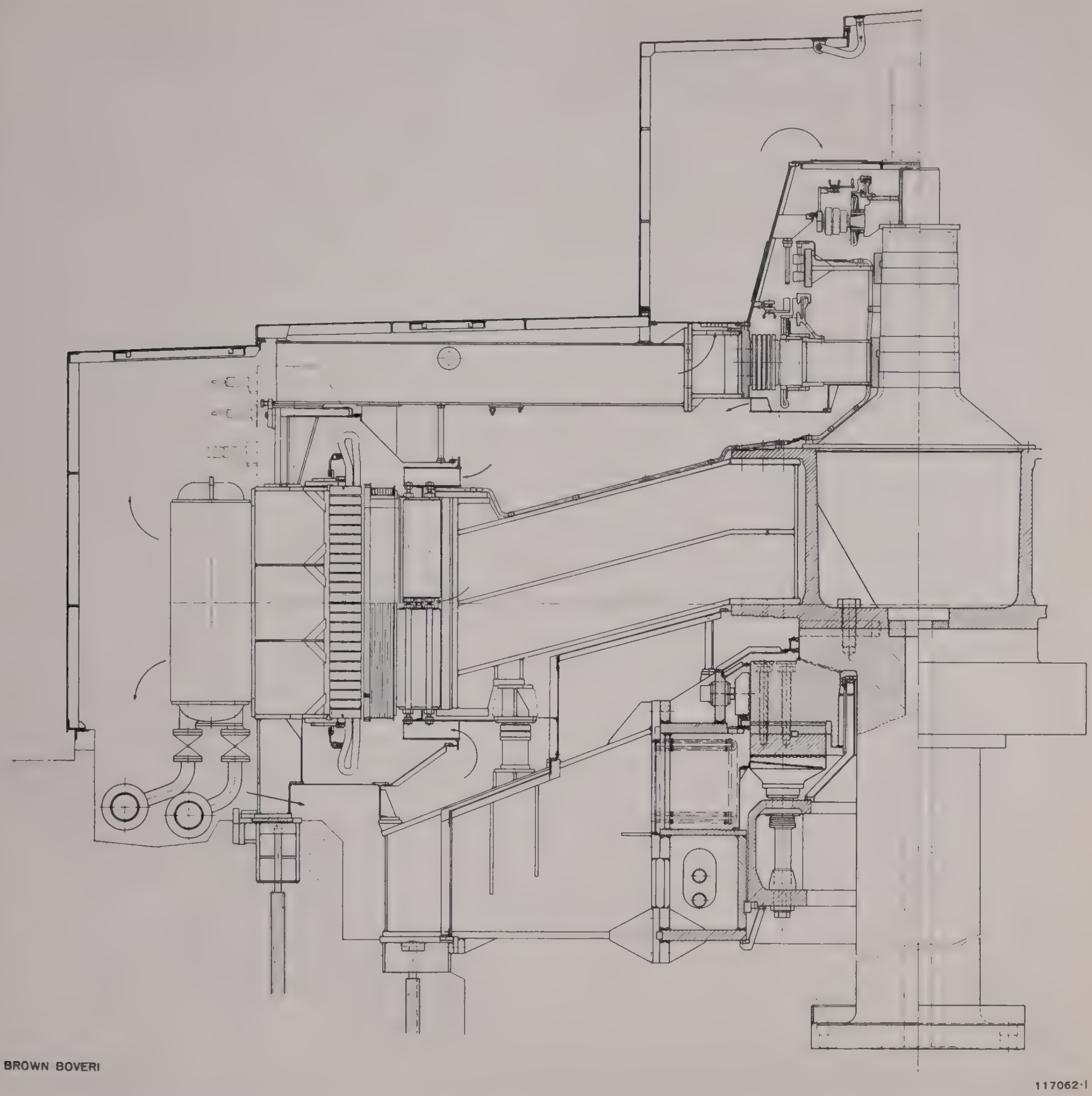

Fig. 40. – Section through a 60-MVA generator, 106 rev/min, 60 c/s, for Wilson Dam power plant of the Tennessee Valley Authority, USA

For inspection the thrust bearing is lowered.

A study of the economics of d.c. generation proved that, for this electrolysis plant with its predominant demand for direct current, the most economical solution was to install d.c. generators, and that it is also preferable to employ direct-coupled slow-running machines rather than high-speed machines driven through gearing.

To afford a certain reserve capacity in an emergency, a 600-kW motor-generator set was installed, the synchronous machine of which is connected to the local a.c. supply system. When Schiffmühle is generating surplus energy this can be returned to the a.c. network through the converter set. This set is also used to feed the a.c. auxiliaries in the factory.

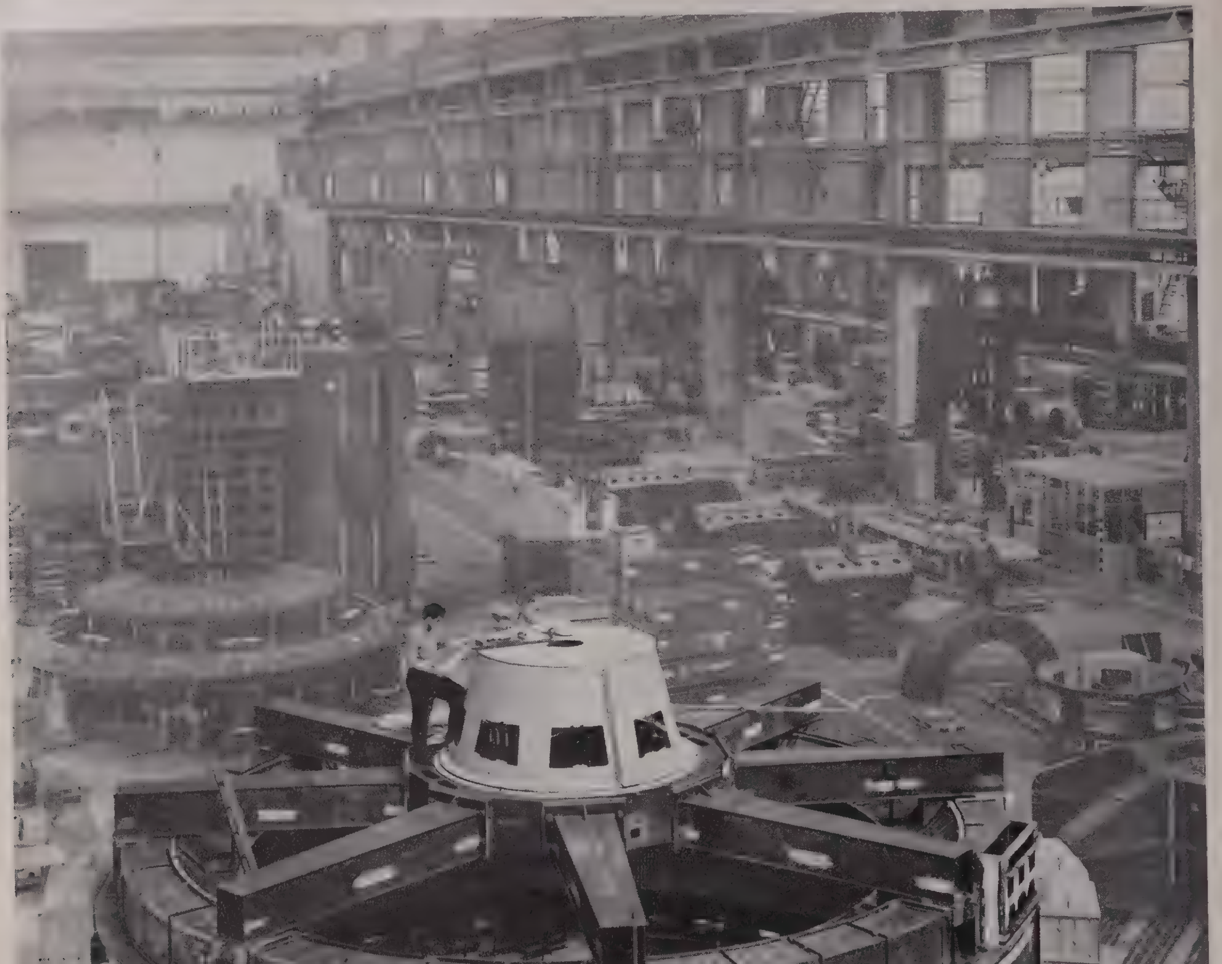

Fig. 41. – One of the three generators for Wilson Dam during assembly in the factory

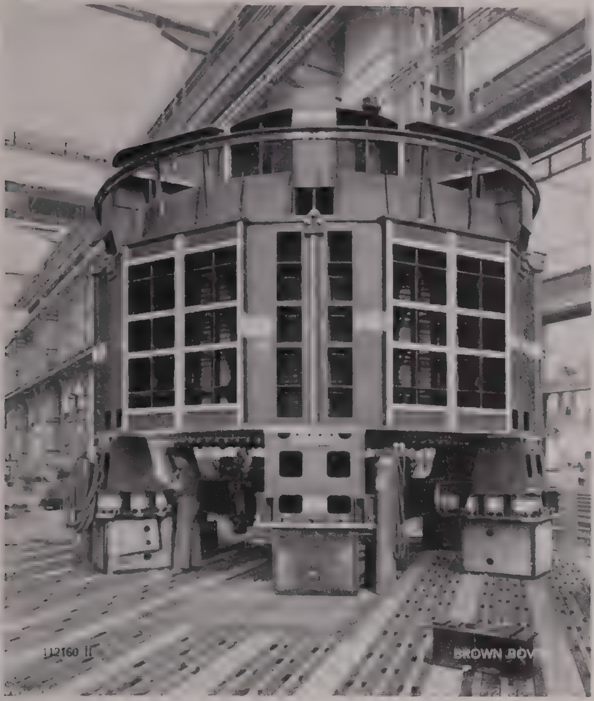

Fig. 42. – One of the four 120-MVA alternators, p.f. 0·8, 375 rev/min, being built for Tokke power station of the Norwegian Hydro-Electric Board

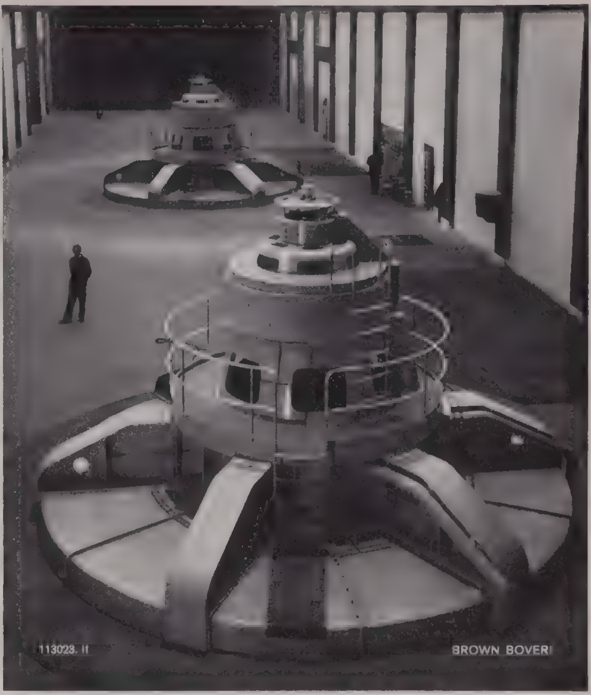

Fig. 43. – Two generators rated 115 MVA, 333 rev/min in Grosio power station of AEM, Milan, Italy

These are the world's largest vertical hydro-electric generators driven by Pelton turbines.

3. Control in the Generation and Distribution of Electricity

3.1 Control and Excitation of Synchronous Machines

The transistor has now become an indispensable element in all branches of electronics. Its rapid progress in the field of control amplifiers is proof of the enormous advantages it offers for certain applications. It has also been successfully employed for voltage control of generators. The transistorized

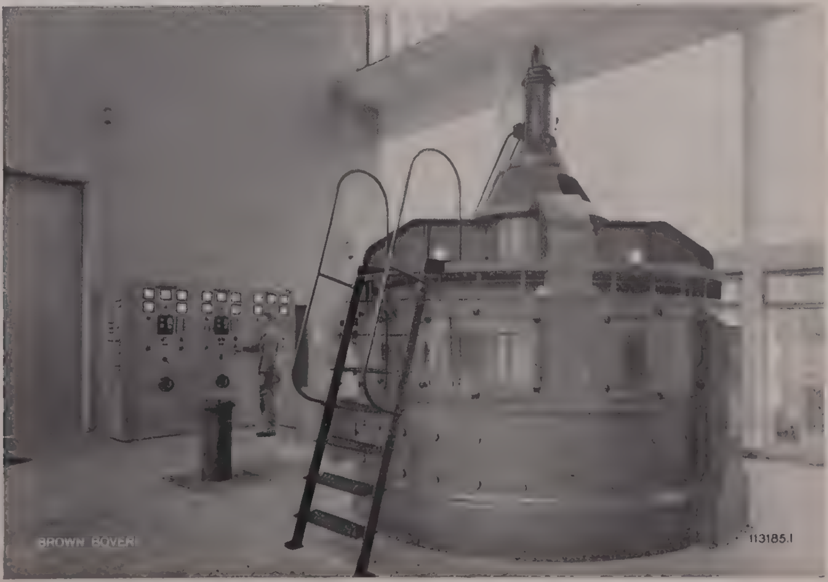

Fig. 44. – One of the two vertical d.c. generators rated 1125 kW, 225 V at 95 rev/min, installed in the Schiffmühle station belonging to Elektrochemie Turgi, Switzerland

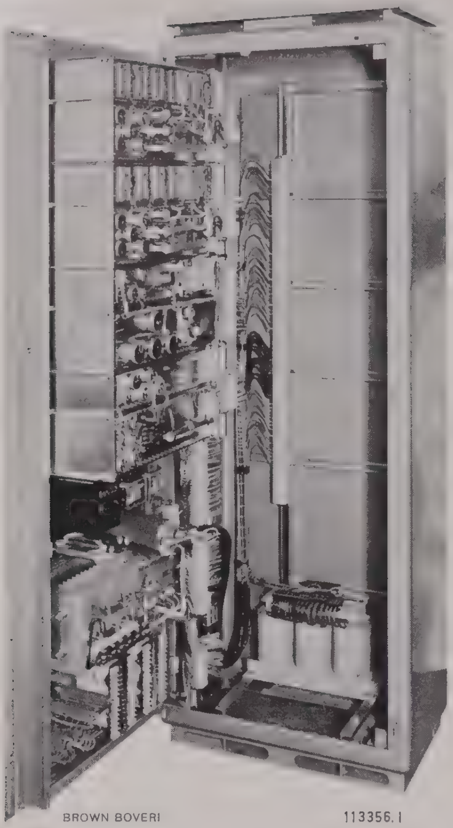

Fig. 45. – Transistorized voltage controller with push-pull output—front view

The cabinet door has been removed. The individual chassis are mounted in solidly-built hinged frames. Each chassis is covered with a front plate.

controller (Fig. 45) developed by the Company has a two-step action and push-pull output.[15]

3.1.1 *Transistorized voltage controller*

From the dynamic aspect, load shedding at the end of a long transmission system imposes the severest demands on a voltage regulator. This kind of disturbance necessitates very rapid de-excitation of the generator which, when the rotor has a high time constant, can only be achieved by a strong negative displacement of the controller. For this reason the positive and negative output of the power stage of the transistorized controller are designed for the same power.

The modern trends in the construction of electronic apparatus governed the design of the transistorized controller. The arrangement of the elements on separate chassis, which are then mounted in a hinged frame (Fig. 45), is very practical for manufacture and operation. It affords ready access to all the components. The cabinet in which the transistorized controller is housed is identical with those used for Brown Boveri carrier equipment and the turbine governors and system controllers.

Fig. 46 shows a block diagram of the voltage control system in Grosio power station of the Milan municipal electricity undertaking (AEM). There the two 115-MVA machines of the first phase are equipped with transistorized controllers. The push-pull amplifier Y acts on the field windings of the boosters B_1 and B_2, driven by the motor C and, in series, used to feed the field of the main exciter. In the present case the motor C and the supply unit N are fed from the generator system H_1 or from the general station auxiliary network H_2. If possible, however, a shaft-driven generator is used to feed C and N. Three feedback circuits help to stabilize the control circuit. Should conditions in the power system make it necessary, the transistorized controller can always be combined with a stability angle limiter W. The generators are run up or down with automatic voltage control; manual control is only employed in an emergency. It is, however, possible to switch over from automatic to manual control at any time and, if the voltages are correctly matched, this change does not produce any surges.

The oscillogram in Fig. 47 shows the disconnection of a purely inductive load; it was recorded during the commissioning of Grosio power station. From the shape of the curve of the controlled output voltage U_R it can be seen that the controller functions almost instantaneously, changing immediately to its maximum negative value when interruption occurs. The extremely rapid build-up of the booster voltage U_B causes the voltage U_E of the main exciter to be reduced very rapidly indeed. With the aid of the feedbacks the control system can be adjusted so that,

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[15] A. DUDLER: Tests on various methods of voltage control for use with large generators. Brown Boveri Rev. 1960, Vol. 47, No. 5/6, p. 361–70.

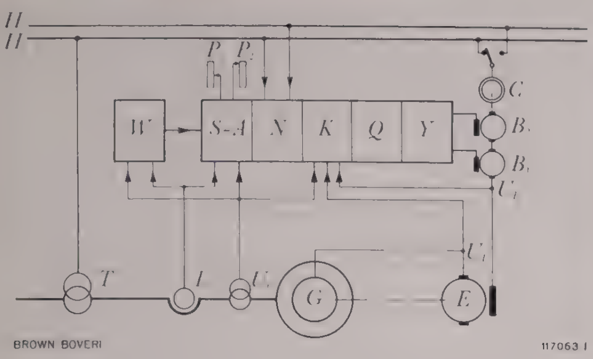

Fig. 46. – Block diagram of the voltage control system with transistorized controller, in Grosio power station of the Milan municipal electricity undertaking (AEM), Italy

B_1, B_2 = Boosters
C = Drive motor
E = Main exciter
G = Generator
T = Transformer for auxiliary generator network H_1
H_1 = Generator network
H_2 = Auxiliary network
S–A = Desired-value—actual-value bridge
N = Supply unit
K = Feedback unit
Q = Trigger and phase reversal stage
Y = Transistorized push-pull amplifier
P_1 = Potentiometer for run-up
P_2 = Setting potentiometer
W = Stability angle limiter
U_G, I_G = Voltage and current of generator

after a disturbance, the generator voltage U_G returns assymptotically to its desired value as in the oscillogram, or with one under- or over-swing.

When the transistorized controller was being developed, great importance was attached to reliability and ease of operation, apart from the response. Thus the controller meets all requirements of modern power station service.

3.1.2 Transductor controller

Resulting from the fact that the magnetic amplifier can be built to handle quite appreciable powers, the transductor controller may be employed with advantage in situations where intermediate exciters are deprecated, i.e. where the controller has to influence the main exciter direct. In this system a multi-stage cascade of amplifiers is employed, with which the comparison between actual and desired values can be performed at a very low power level, in spite of the high output power, thus keeping the response time short. The output stage can be taken from the standardized range of magnetic amplifiers, and is thus largely adaptable to the exciter involved.

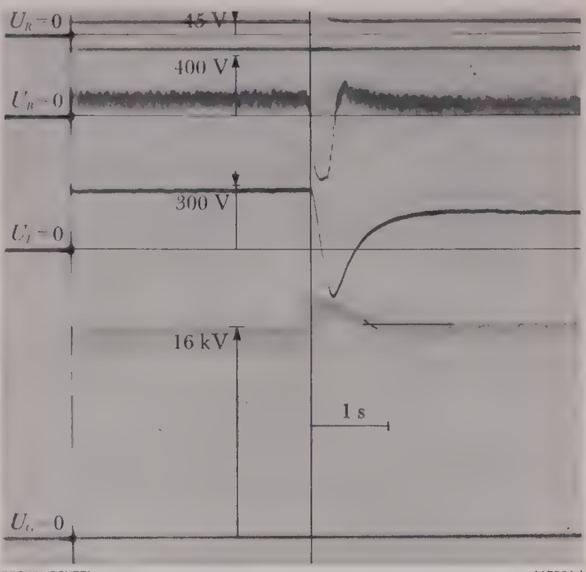

Fig. 47. – Oscillogram of disconnecting inductive reactive load utilizing the control circuit in Fig. 46

Generator: 115 MVA, 16 kV, 4150 A, p.f. 0·9
Inductive reactive load interrupted: 75 MVar

U_R = Output voltage of push-pull amplifier
U_B = Voltage of booster set
U_E = Voltage of main exciter
U_G = Generator voltage

To illustrate this point, mention may be made of a transductor controller supplied for a 75-MVA turbo-alternator which came into service recently in Tacoa power station in Venezuela. It contains a three-stage push-pull magnetic amplifier cascade, whose output acts on the two separately excited field windings of the exciter. The latter also has a series winding which produces 100 % field. The input to the first amplifier stage experiences the voltage difference between the actual and desired values, as well as three differential feedbacks for stabilization. The controller's circuitry corresponds to that described in an earlier article (see footnote 15).

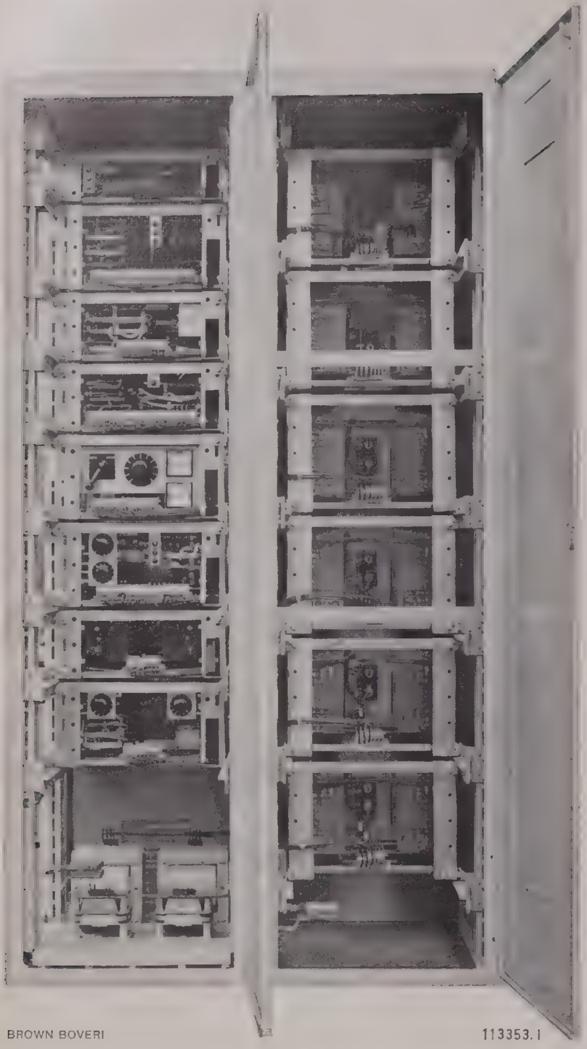

Fig. 48. – Voltage control cabinet at Tacoa power station in Venezuela

In addition to the magnetic voltage controller for the main generator, the cabinet also contains that for the shaft-driven generator. The chassis are contained in draw-out trays so that all components are easily accessible.

To feed the controller a self-excited shaft-driven generator is provided. It is excited by a compounding circuit and is also controlled by a magnetic amplifier. Thus the entire excitation system is independent of any auxiliary supply.

The controller for the main generator, as well as that for the shaft-driven generator, consists of a number of frame-mounted chassis incorporated in draw-out trays of a two-section control cabinet (Fig. 48). By making the chassis withdrawable, all components become easily accessible. Before the controller was taken into service it was tested with the analogue computer, used to simulate the generator and series exciter. Great stress was laid on adjusting the stability to conform to the conditions actually experienced in service. Fig. 49 shows an oscillogram of shedding an inductive reactive load of 56 MVar. The settling time is only 0·48 s, which may be considered remarkably short, in view of the size of the machine.

The magnetic voltage controller possesses excellent properties as regards speed of control and stability. In those cases where the fields of the exciter are fed direct from magnetic power amplifiers, an excitation system is obtained which is notable for its reliability and the small amount of attention required.

3.1.3 Rectifier excitation of synchronous alternators

By employing mercury-arc rectifiers to excite synchronous alternators it is possible to fulfil extremely stringent requirements from the control aspect, such as are stipulated for certain industrial installations. This system may also be interesting for power stations where it is difficult to fit a main exciter, e.g. for large turbo-alternators or slow-running machines, especially those with the rotor above the main bearing.

The installation to which reference will now be made is in Sweden, where it supplies power for a rolling mill. The synchronous machine in this case is a 37·5-MVA alternator driven by a gas turbine. The operation of the rolling mill produces heavy reactive load surges. As proved by investigations of the operating conditions, using the analogue computer in conjunction with the network analyser, the only way to keep the voltage fluctuations within the specified, close limits on the h.v. side of the plant was to employ rectifier excitation.

With a control system of this kind the transients are determined almost solely by the machine constants and the ceiling voltage of the excitation system. In the installation considered the latter

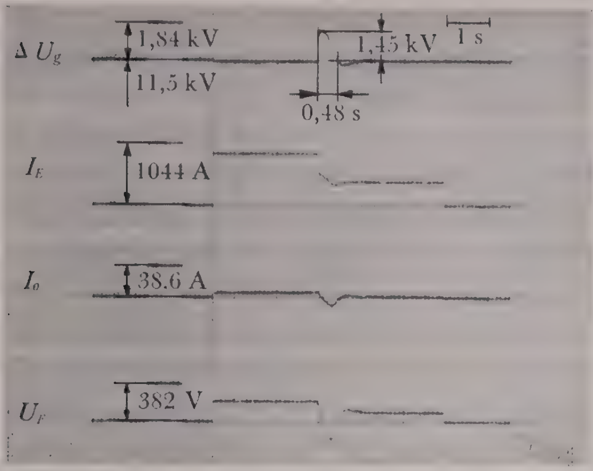

Fig. 49. – Oscillogram of shedding an inductive reactive load of 56 MVar employing the controller in Fig. 48

Generator: 75 MVA, 11·5 kV, 3770 A, 50 c/s, 3000 rev/min. This test was carried out with the aid of the analogue computer, on which the generator and exciter were simulated.

ΔU_G = Deviation in generator voltage
I_E = Rotor current
I_e = Difference between the two output currents of the push-pull controller
U_E = Exciter voltage

corresponds to three times the rated exciter voltage. Thus the abrupt increases in voltage can be kept to the theoretically attainable minimum and corrected in a very short time. Fig. 50 shows the voltage variation during a load throw-off test with a 5000-kVA machine excited by the above excitation and control system.

Fig. 51 shows the block diagram of the installation. From the reference-value unit 1, the continuously variable desired value (from 20 to 110%) proceeds to the stabilizing filter, where it is compared with the rectified actual value of the generator voltage. After the filter, which has a proportional-integral-derivative (PID) action, the difference between actual and desired values passes to the electronic regulator 4, where the signal is amplified so that it can drive the transistorized grid control set 5. The six pulse output stages of the grid control set are connected direct with the grids of two parallel six-anode rectifiers 6, feeding the rotor of the synchronous machine 10.

With the described system of excitation it is possible to attain very high gains without experiencing any stability difficulties. At the plant in question we were content with a gain of 200. The apparent deviation from proportionality which can be seen in Fig. 50 was caused by the superposition of a disturbance value related to the current.

The high ceiling voltage of the excitation system, which is very important indeed if short control times are to be obtained and the voltage maintained in the event of a short circuit, is accompanied by the risk of the excitation current appreciably exceeding its rated value if the fault is of long duration. To avoid imposing a thermal overload on the rotor, however,

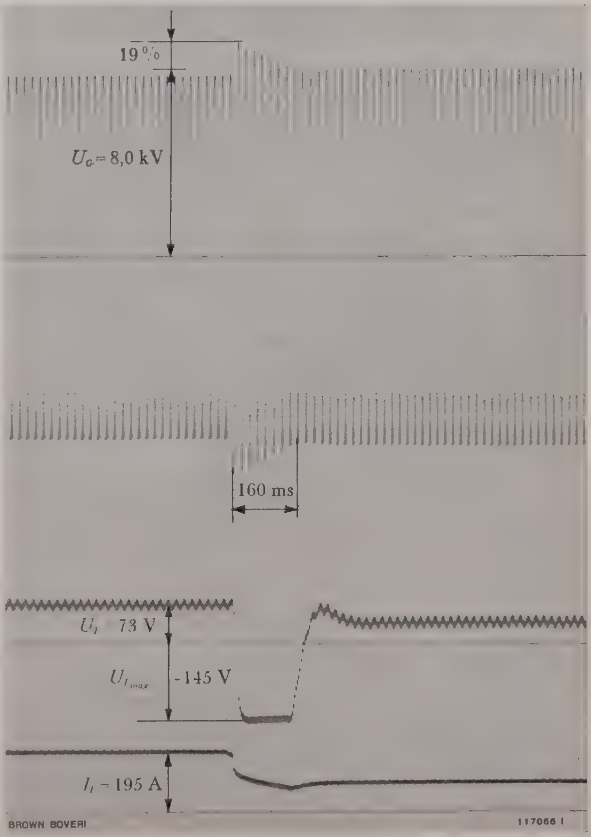

Fig. 50. – Oscillogram of a load throw-off test, using the control system in Fig. 50. The inductive load shed amounts to 50% of the rated current of the generator

Machine data: 5000 kVA, 8 kV, 360 A, 50 c/s.
U_G = Generator voltage
U_E = Exciter voltage
I_E = Excitation current

[illegible]itation circuit contains an overcurrent relay [illegible]h actuates the electronic limitation of the excitation current after a time-lag inversely proportional to the current. This limitation, which is ineffective under normal conditions, intervenes via the d.c. current transformer 7 and the associated auxiliary unit 8 in such a manner in the voltage control circuit that it no longer controls the generator voltage but regulates the excitation current to its rated value. The rotor is also protected by a lightning arrester and a shorting switch which responds to overvoltage.

3.2 Speed control of turbines

3.2.1 Governors for water and steam turbines

In the past two years quite a large number of electric turbine governors of the same type have been taken into service with various kinds of water turbines. The operating staff in the power stations have expressed their entire satisfaction with the function and manipulation of this governor, which has been reflected in the rising turnover. In order to benefit from the advantages of electric speed control in steam turbines too, a similar apparatus has been devised for this kind of machine, by means of which the frequency-load characteristic can be accurately linearized. Moreover, the electric governor for use with steam turbines is equipped with a means of limiting sudden changes in load (Fig. 52). With this device it becomes possible to utilize steam turbines for system control without running the risk of overtaxing them.

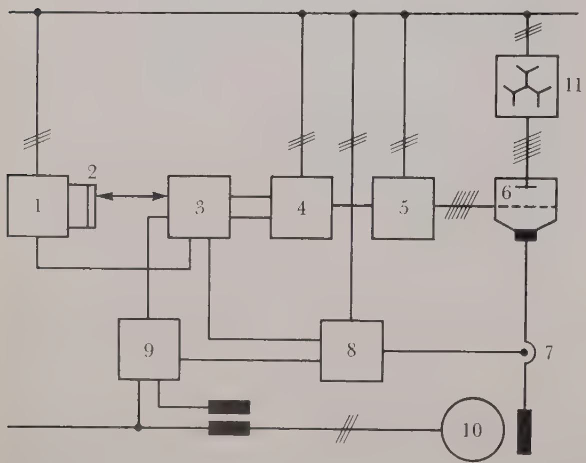

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Fig. 51. – Block diagram of the control for a rectifier-excited synchronous alternator

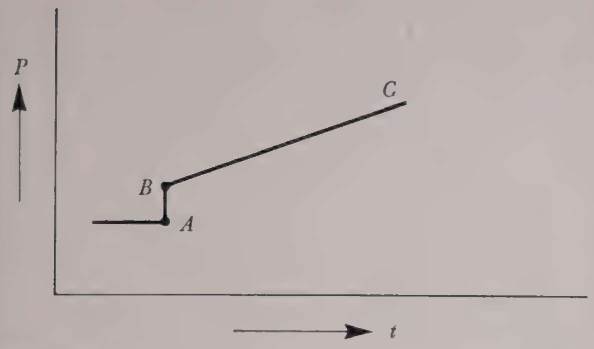
1 = Desired-value unit
2 = Potentiometer for setting desired value
3 = Stabilizing filter
4 = Electronic controller
5 = Grid control set
6 = Mercury-arc rectifier
7 = D.C. current transformer
8 = Auxiliary unit for 7
9 = Actual-value unit
10 = Synchronous alternator
11 = Triple-star connected transformer

3.2.2 Centralized control of power stations

With the electric turbine governor it is possible to equip the power stations very simply with a joint means of adjusting the desired value for any number of generator sets, i.e. to provide centralized control. By replacing the manually controlled central adjusting element by an appropriately designed regulator, we arrive at centralized control for the power station. A typical centralized controller is designed to provide the following facilities:

- Load-dependent frequency control with centrally variable offset, with or without choice of bent characteristic.
- Pure load control with adjustable, temporary frequency assistance (of particular interest for "run-of-the-river" plants).
- Pure frequency control.
- Control of tie-line power, with or without frequency control.

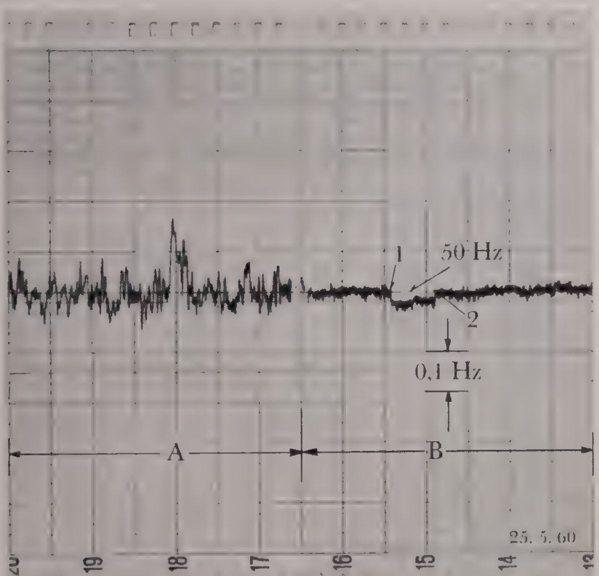
This universal system of centralized control with its facilities for adjustment can draw every machine into system control without any technical or economical disadvantages resulting for the service. Thus, for instance, machines in run-of-the-river plants can also be called upon for temporary frequency assistance.



BROWN BOVERI 117067·1

Fig. 52. – Limitation of load surges by a steam turbine governor. Showing the variation of the load P when the desired value is abruptly changed

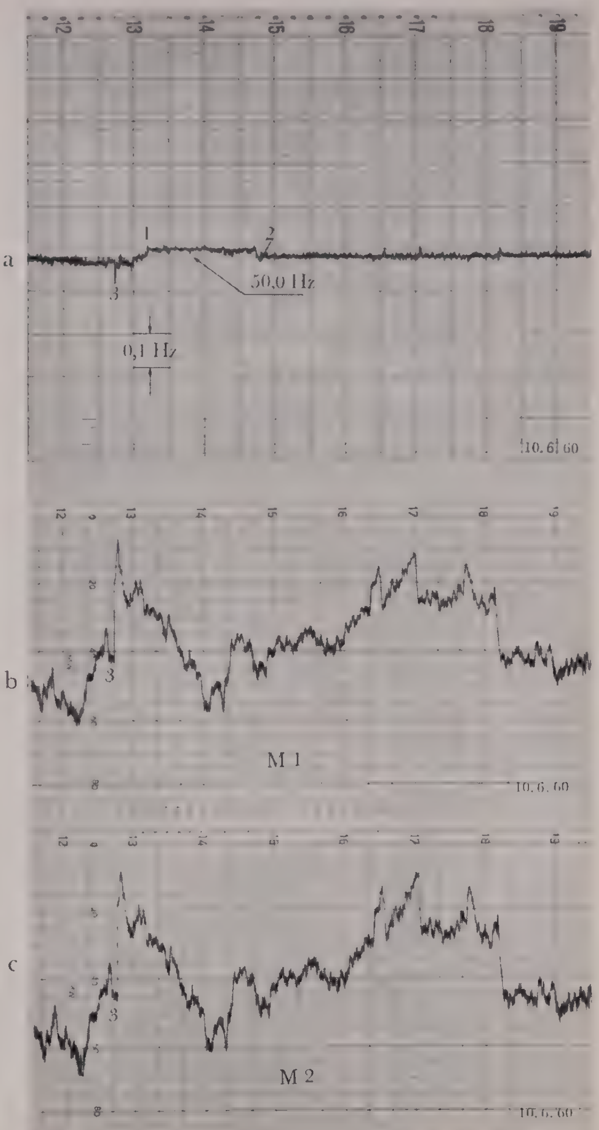
AB = Region of abrupt load change
BC = Limited load change per unit time (MW/min)



BROWN BOVERI 117514·1

Fig. 53. – Frequency control in the power system in eastern Norway

Part B = Frequency maintenance by two 70-MW sets equipped with electric governors
1, 2 = Desired frequency changed



BROWN BOVERI 117515·1

Fig. 54. – Frequency control by a centralized controller with two 70-MW generator sets

a: Frequency (in c/s)
b: Power output of the first machine M_1
c: Power output of the second machine M_2
1, 2 = Desired frequency varied
3 = 75 MW load shed in network

In the power system of eastern Norway an opportunity arose for obtaining some interesting measurements with a centralized control system of this kind. The machines available were two 70-MW generating sets. From time to time these machines have to maintain the frequency in the network. The frequency trace on the chart (Fig. 53) shows that the frequency is well maintained, which is only possible by using the electric speed governor. In the case illustrated one regulator operates with integral action while the other has the normal offset of 4 %. In comparison the frequency trace in Fig. 54a shows the variation in equency when the central regulator is made to trol the frequency with the two machines mentioned.

Some idea of the magnitude of the power surges and rates of change in this case can be gathered from the associated power trace for these two control sets. Such precise maintenance of the frequency can naturally only be attained with a centralized controller when the turbine governors are also very sensitive.

Similar results were obtained with tie-line power control, with and without frequency control.

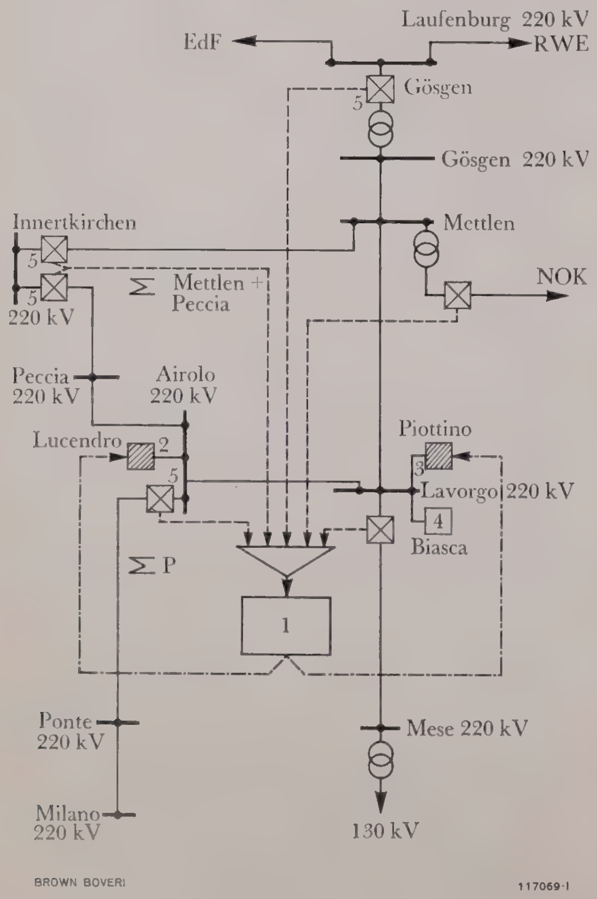


Fig. 55. – Diagram showing the arrangement of telemetering channels of the Aare–Tessin Electricity Co. (ATEL) and Società Edison, Milan, used for tests on the control system

1 = System controller
2 = Lucendro power station
3 = Piottino power station
4 = Biasca power station
5 = Measurands of tie-line power

Centralized control is another step towards easing the interconnected operation of power systems, and may be expected to attract increasing attention in the years to come.

3.3 Control of power transfer

Digital system controller

The increasing growth of interconnected power systems on a national and international basis necessitates extremely accurate maintenance of the set frequency and the agreed power transfer quotas. Within a single network the number of machines in operation and the employment of controlling machines has to be adapted to the loading programme and the transfer quotas, which can vary from one hour to another. In order to control the exchange of power in the best possible manner it is also necessary to adapt the principle parameters to the operating conditions at a particular instant. The primary requisite for this is that the constants of the control system must be adjustable over a sufficiently wide range, as given by calibrated scales on the system controller. The newly developed digital system controller fulfils both the following conditions:

- Accurate calibration and maintenance of the desired values of frequency and tie-line power to within $\pm 2 \times 10^{-5}$,
- The constants are adjustable over a wide range on calibrated scales.

Of the three digital system controllers so far ordered, the first was placed in service last year in the Lavorgo power station of the Aare-Tessin Electricity Co. (ATEL), Switzerland. Having previously carried out exhaustive studies of the relationships between the control parameters and the behaviour of the network and the controlling machines, it was possible to select such settings that controlled operation could be carried out satisfactorily from the very start. The controlled variable is the sum of the tie-line powers from the ATEL to the connected networks.

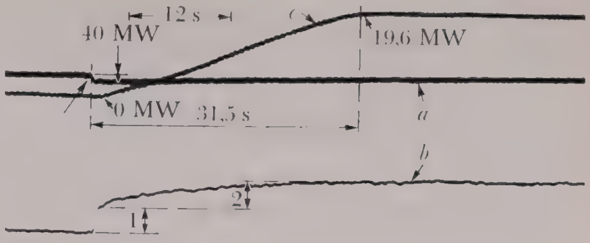
Fig. 56. – Oscillograms of tests on the control system

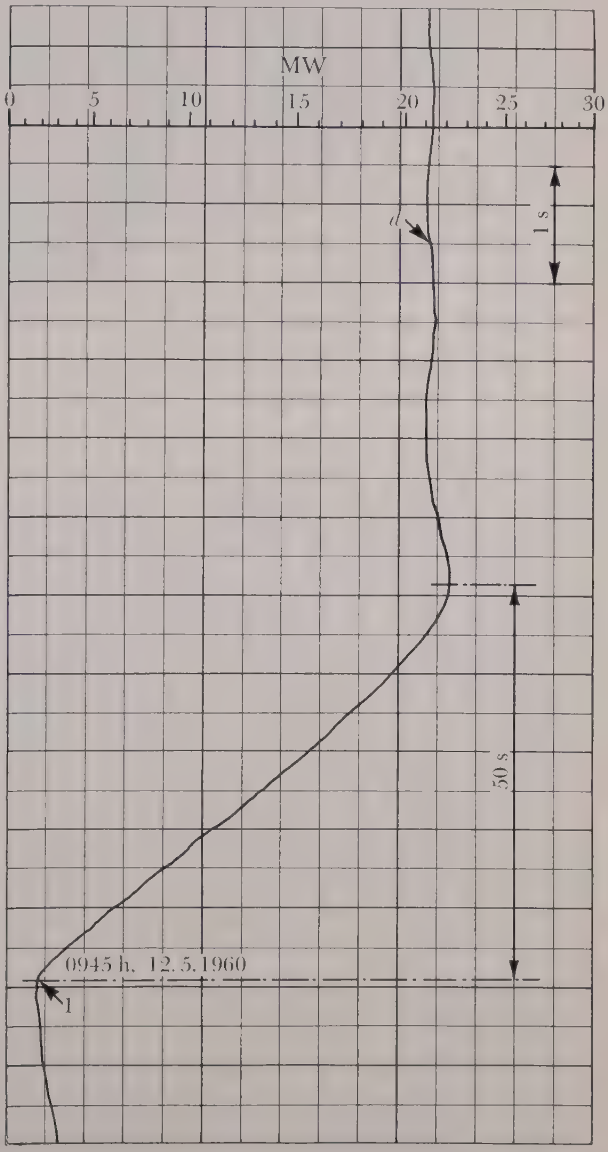
a = Input signal to system controller.
Note the load surge (↗) of 40 MW in Biasca.

b = Correction command imparted by system controller.
1 = Proportional part 50%
2 = Integral part 50%

c = Output of machine 2 in Piottino
(Picks up 19·6 MW in 31·5 s)

d = Output of machine 1 in Lucendro
(Picks up 20·4 MW in 50 s)





First of all, two 25-MW sets driven by Francis turbines in Piottino generating station were utilized for control. Originally Lucendro was also planned as a controlling station, but the plan was dropped a few years ago owing to unfavourable conditions in the pressure tunnel. However, after exhaustive investigations into the relationships between the control constants and the pressure fluctuation in the tunnel, it proved possible to utilize the two 30-MW sets driven by Pelton turbines for control purposes, given favourable settings on the digital system controller. On May 12th 1960, ATEL carried out a series of load tests to check the operation of the controller. The state of the network and the system of transmitting the telemetered values of tie-line power are illustrated schematically in Fig. 55. For these tests the controlling machines were one in Piottino and one in Lucendro. In order to initiate a control action, a 40-MW generator in Biasca was disconnected, the settings on the controller being: $C_p = 0{\cdot}5$ = proportionality constant, and the integral action time $T_n = 10$ s.[16]

From the oscillograms in Fig. 56 it can be seen that the generator in Piottino picked up its share of the load, i.e. 19·6 MW, in 31·5 s, while the machine in Lucendro picked up 20·4 MW in 50 s. From the record of the correcting command imparted by the system controller it can be seen that in the correction of the tie-line power, almost the limit of aperiodic response was attained, i.e. rapid correction without overswing.

Apart from the results of the trials, operating experience gained with the controller in Lavorgo has confirmed the universal applicability of the al system controller (see Fig. 57), owing to the ease with which the control parameters can be set and to the high constancy of the desired values.

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[16] W. EGLI: The electronic digital system controller. Brown Boveri Rev. 1960, Vol. 47, No. 10/11, p. 741.

Soon after the first system controller was taken into service at Lavorgo, a second was commissioned by the Elektrizitätsgesellschaft Laufenburg, a third being delivered to the Grande Dixence S.A. in the autumn of 1960.

4. Control Rooms

In the last review of technical progress[17] mention was made of the system of *preselector push-button control* used in a large substation. Here attention is drawn to an example in which this principle of control has been adopted in an extended sense. When the whole installation is finished, it will be possible to control four hydro-electric generating stations with a total of 14 alternators, as well as a 115-kV switchyard, using preselector control from a single control room.

The stations in question are situated on the River Guadalupe in Colombia and are connected with the control building some 3–5 km distant and about 600 m higher merely by a pair of 54-core telephone cables, reserved for control duties. The control room contains a desk with two identical but independent working positions (Fig. 58), and an indicator panel consisting of several sections, with single-pole mimic diagram, position indicators, as well as indicating and recording instruments (Fig. 59). The necessary selecting and control contactors are accommodated in the cable passage immediately below the control room floor. To simplify the layout of the control gear,

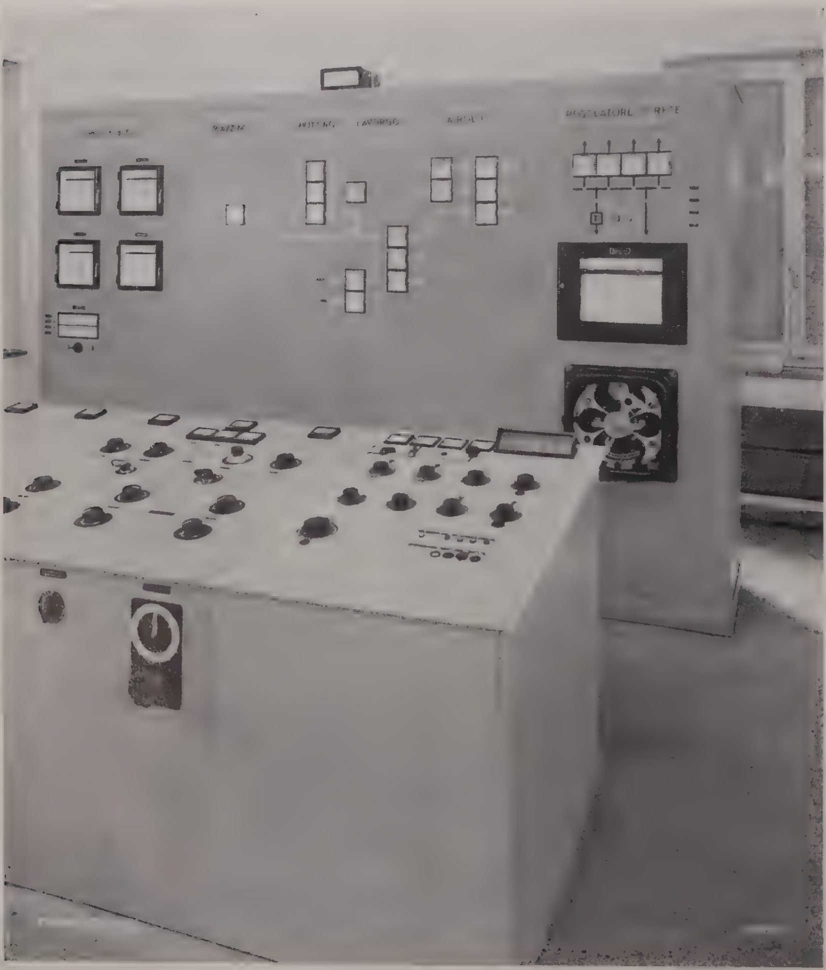

Fig. 57. – Desk of the system controller in Lavorgo substation

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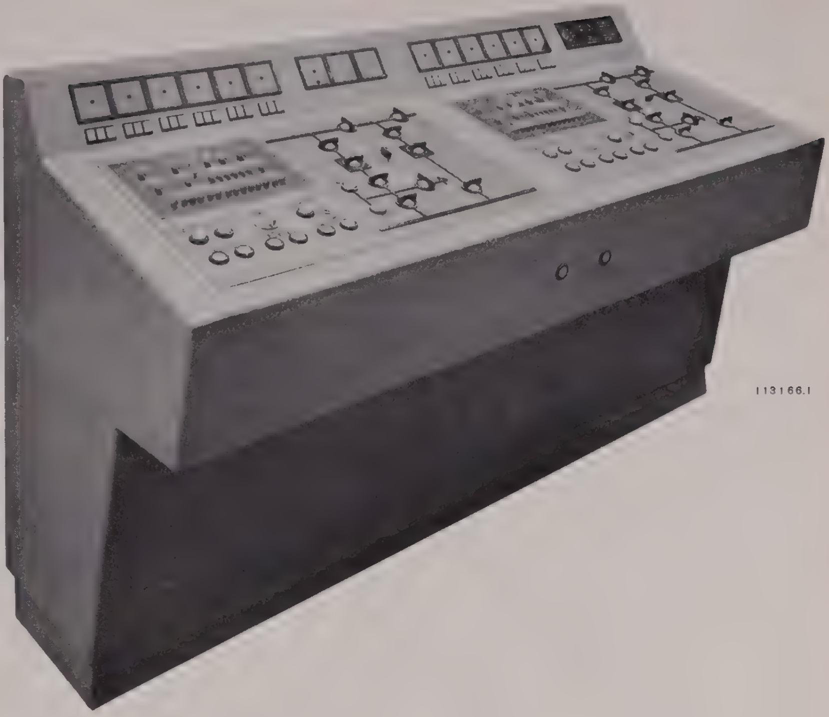
[17] See Brown Boveri Rev. 1959, Vol. 46, No. 1/2, p. 43.

Fig. 58. – Control desk for the preselector push-button system employed for controlling the Guadalupe group of power stations in Colombia

Each of the two independent working positions on the desk contain:

Bottom left:	push-buttons for controlling the 14 alternators
Centre left:	preselector buttons for the 14 alternators and the feeders of the switchyard
Right:	mimic diagram with control and acknowledgement switches
At the top, in the projection:	indicating instruments with illuminated scale factors



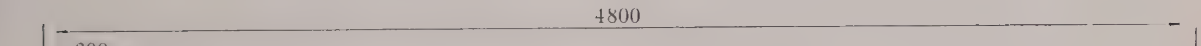


Fig. 59. - Acknowledgement signal panel in the central control room for the Guadalupe group of power stations in Colombia

The 22-part board contains the mimic diagram, acknowledgement lamps and indicating instruments in the centre section. The installation attends to four generating stations and a switchyard. At the sides are the panels for signalling, summation, for the auxiliaries and for synchronization.

n of single preselector control was adopted in ase. The desired branch, which may be an incoming or outgoing transmission line, or a generator, is selected by a corresponding button on the control desk. The actual executive command is then given by control and acknowledgement switches or push-buttons common to all branches, thereby operating circuit-breakers or isolators, or giving commands to turbine governors or the alternator regulators. The largest of the four stations, which will eventually have six 54-MVA alternators with a service voltage of 13·8 kV, is normally unattended. The turbines and alternators can be started, stopped and controlled automatically from the control room. All acknowledgement signals and measurands from the stations to the central control room run through the preselector system. This is designed to operate on 60 V d.c., thereby allowing low-priced telephone cables to be used.

For the transmission of disturbance signals a 30-core cable for 125 V d.c. is used. Depending on the nature of the disturbance or fault, or the degree of urgency with which it should be eliminated, it is brought to the attendant's notice in one of three groups, or the necessary switching operation is automatically carried out. For the outdoor switchgear, situated in the immediate vicinity of the control building, the auxiliary supply is at 125 V d.c., with which the switchgear can be controlled direct, thus avoiding the need to transform the low voltage normally employed for the preselector system up to the value needed to operate the switchgear.

II. DISTRIBUTION AND CONVERSION OF ELECTRICITY

A. Switchgear and Protective Gear for High and Medium-Voltage Networks

The field of high and medium-voltage switchgear has always been noteworthy for the wide variety of the requirements from the operational aspect, having regard to the ever-increasing needs of the power supply undertakings. Intensive efforts are necessary on the part of our research and test laboratories, to improve physical knowledge and to investigate the technical possibilities, which are subsequently embodied in our designs. The knowledge so gained is also continually checked by trials under service conditions. All possible switching operations likely to be experienced in service can be dealt with reliably by switchgear manufactured according to modern batch-production principles. This renders any individual component or even complete sub-units completely interchangeable.

1. Airblast Circuit-Breakers

Once again it has been confirmed that arc extinction by means of compressed air continues to maintain its superiority over all other methods. This is borne out by the fact that an increasing number of European and overseas manufacturers are going over to this system, as well as the principle of multiple interruption introduced by Brown Boveri 20 years ago. The decisive factor, though, is that our clients are able to profit from the many years' experience from research and practice on which our designs are based.

1.1 Outdoor airblast breakers

Characteristic features of current development are the increasing breaking capacities and the tendency to raise transmission voltages. These are not likely to stop at 400 kV, but will probably be raised to 650–750 kV in the near future.

The two breakers rated 20 000 MVA and 2000 A supplied to the first 380-kV transmission link in Germany, between Rommerskirchen and Hoheneck, and described in the review two years ago, have given excellent results in service. As a consequence, the Rheinisch-Westfälisches Elektrizitätswerk AG. has ordered five more breakers of the same type. For the new 380-kV transmission system in Switzerland eight breakers rated 12 000 MVA and 1200 A have been ordered, some of which have already been delivered.

Of approximately one hundred 220-kV breakers with a breaking capacity of 10 000 MVA which have been ordered for Switzerland, the greater part have already been delivered and taken into service. Colour plate VII shows the switchyard at Sils belonging to the Kraftwerke Hinterrhein AG., where there are twelve triple-pole breakers of this type.

Fifteen breakers for a service voltage of 275 kV, with a breaking capacity of 7500 MVA and capable of carrying a rated current of 1000 A have been supplied to South Africa. Fig. 60 shows some of these breakers in the Highveld switching station of the Electricity Supply Commission (ESCOM).

Thus, in conclusion, it may be stated that, owing to the neatness of the airblast principle, its simplicity and reliability, breakers of this kind have been able to assert their superiority in installations at home and abroad under a wide variety of operational and climatic conditions.

1.2 Indoor airblast breakers

Owing to its ability to fulfil the most stringent requirements, the indoor airblast breaker continues to lead the field for high and medium breaking capacities and current ratings. Our design of breaker has

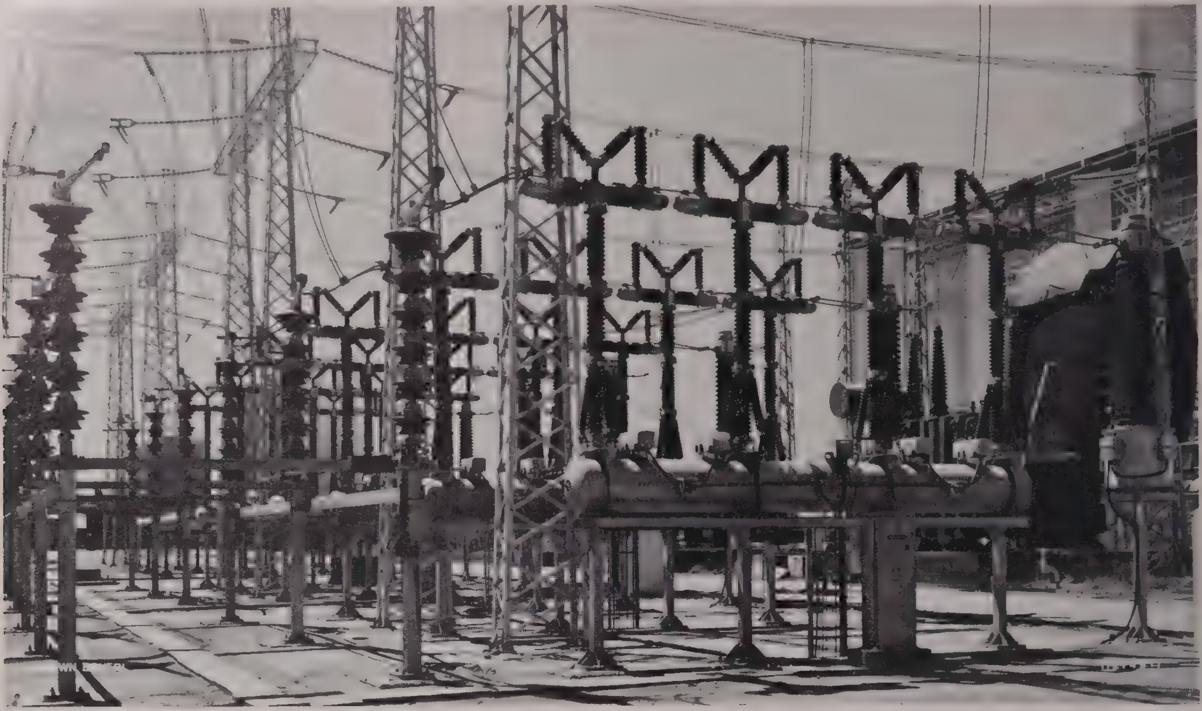


Fig. 60. – 275-kV airblast breakers in the Highveld switching station of ESCOM (South Africa)

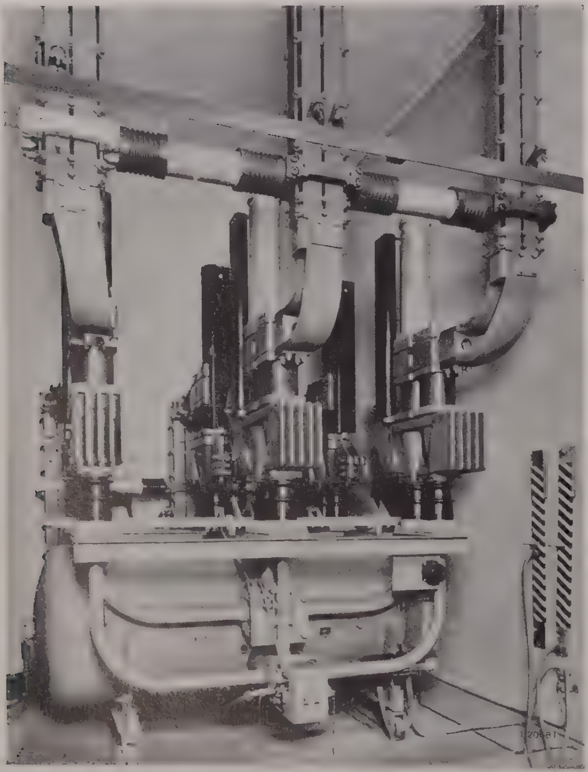


Fig. 61. – Triple-pole high-power airblast circuit-breaker type DB, rated 20 kV, 6000 A, 2000 MVA, in a power station of the Swedish State Power Board

also proved ideal for incorporation in open-type or metalclad installations. An increasing number of these breakers have found employment with electric furnaces at home and abroad. Their suitability for dusty situations is undisputed. The fact that these breakers are designed on the unit construction principle has brought in a number of orders. A case in point is one for five high-power breakers type DB for a service voltage of 18 kV, a breaking capacity of 2000 MVA, for a maximum service current of 5050 A and a peak making current of 320 kA. Fig. 61 illustrates a breaker of this kind installed in a power station of the Swedish State Power Board. The same client has also taken eight double-pole high-power breakers for 18 kV, 6000 A into service, capable of breaking a symmetrical current of 100 kA, with a peak making current of 255 kA (Fig. 62); a bank of three such breakers can handle symmetrical loads of up to 5400 MVA.

For a thermal generating station at Leghorn in Italy a generator breaker composed of three single-pole units for a service voltage of 16 kV is under construction at present; the triple-pole combination will have a breaking capacity of 2500 MVA at 15·75 kV.

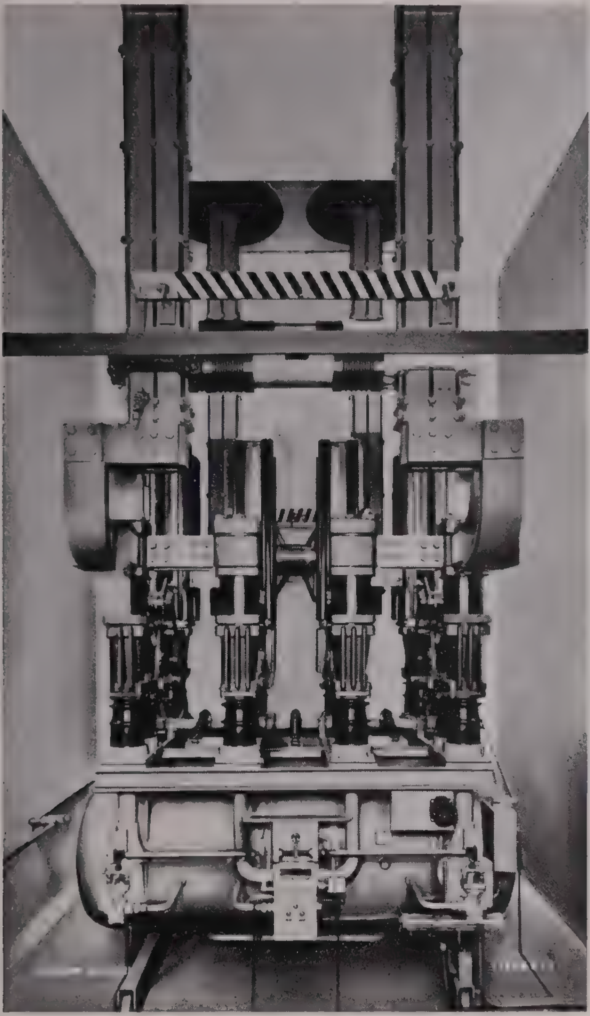


Fig. 62. – Double-pole high-power airblast circuit-breaker type DB, rated 20 kV, 6000 A, 1800 MVA, in a power station of the Swedish State Power Board

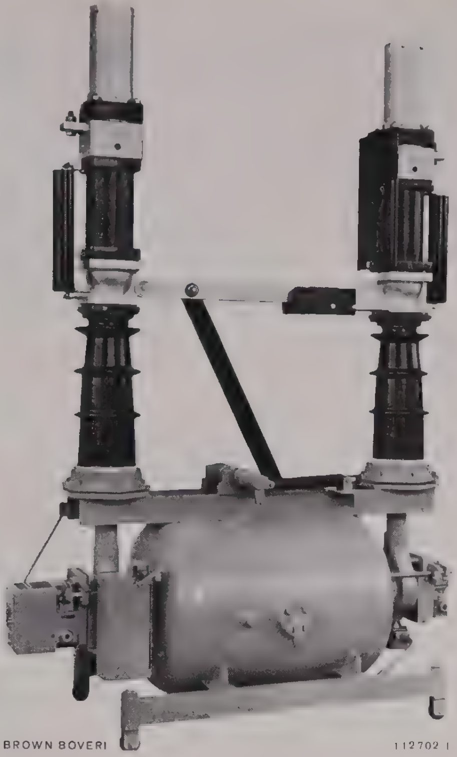


Fig. 63. – Single-pole airblast circuit-breaker type DB, rated 60 kV, 1000 A, 1250 MVA, supplied to PEGUS, Utrecht, Holland

Fig. 63 shows one of eight airblast breakers for a current rating of 1000 A and a single-phase breaking capacity of 1250 MVA, being built for the Provinciaal en Gemeentelijk Utrechts Stroomleveringsbedrijf (PEGUS), some of which have already been delivered.

2. *Magnetic Circuit-Breakers*

The range of magnetic circuit-breakers, batch production of which commenced in 1958 with units for 3·6–7·2 kV,[1] has since been extended to cover the voltages 12–17·5 kV. Fig. 64 shows the modern, well-equipped assembly bay in the factory where these breakers are put together. Already a considerable number of these breakers are in service in many parts of the world, including, in addition to European countries, North and South America, India, Japan, South Africa and the Near East. This type of breaker, which requires a minimum of maintenance, has proved particularly successful in installations where frequent operation is a feature. Several electric furnace plants at home and abroad, with voltages ranging from 3 to 13 kV, are equipped with our magnetic circuit-breakers. Fig. 65 shows the oscillogram of the interruption of an arc furnace in a Swiss steelworks, using a magnetic circuit-breaker rated 3·6 kV, 150 MVA. In the two years during which this breaker has been in operation, it has performed over 10 000 switching actions. Magnetic circuit-breakers can be supplied for open-type installations, or as metalclad switchgear, the preference for the latter form being pronounced at the present time.

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[1] J. Schneider: Design and development of magnetic circuit-breakers. Brown Boveri Rev. 1959, Vol. 46, No. 3, p. 194-203.

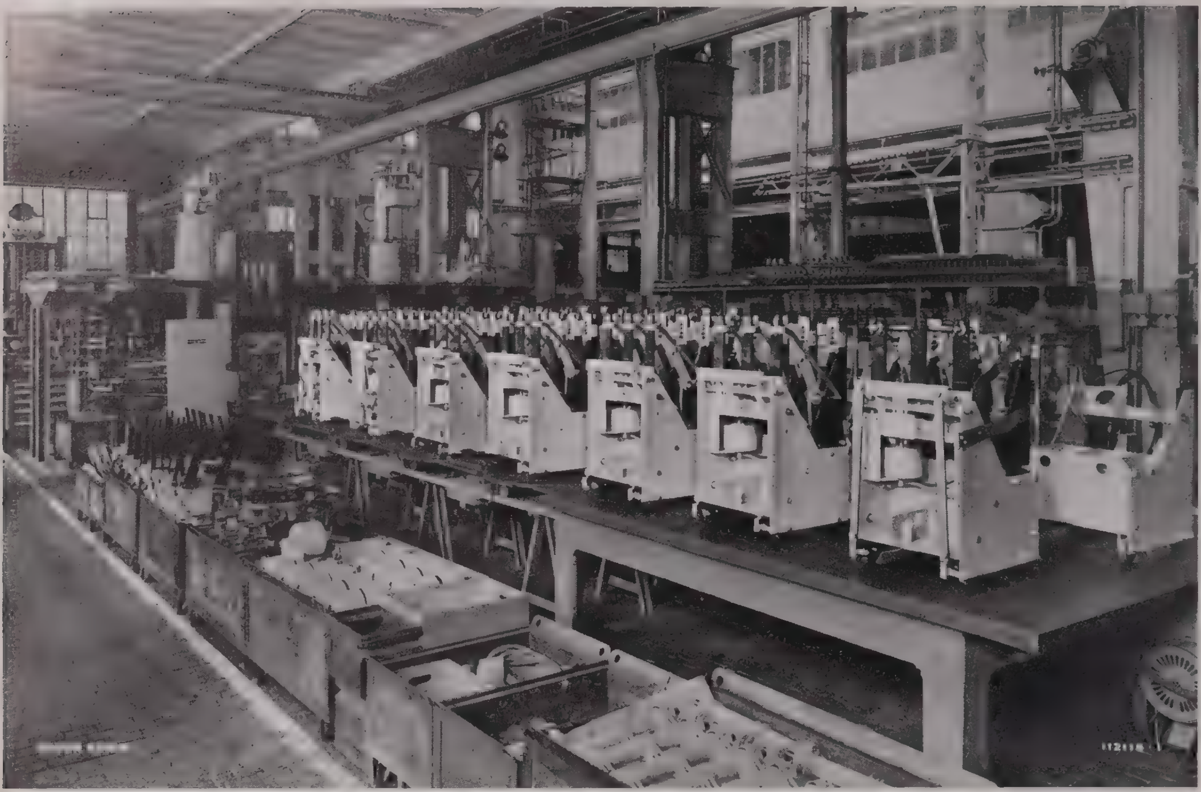

Fig. 64. – Assembly bay for magnetic circuit-breakers in the factory

Special equipment is provided for assembling the trucks, operating mechanisms and arc-chutes.

3. *On-Load Isolating Switches*

For small substations there is an increasing demand for on-load isolators. In order to make allowance for this trend, existing designs have been modernized; the admissible peak value of the making current has been increased to 50 kA. Fig. 66 illustrates the assembly bay for these switches in the factory; it is laid out for the production of batches of up to 500. Modernized designs are now available for ratings of 12 kV, 400 and 600 A. These switches may perform up to 200 interruptions at full capacity without any parts of the contact system having to be replaced. When

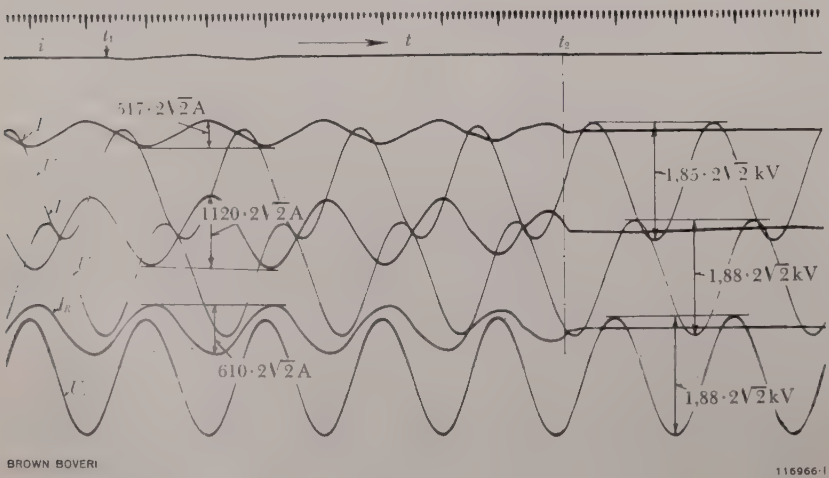

Fig. 65. – Triple-pole magnetic circuit-breaker for 3·6 kV, 1500 A, 150 MVA

Switching trials with an arc furnace. The oscillograms show a partial short-circuit in the furnace; for operational reasons it was impossible to immerse all electrodes fully in the melt.

U_R, U_S, U_T = Phase voltages
I_R, I_S, I_T = Furnace load currents
i = Tripping current
t = Time
t_1 = Order given to trip
t_2 = Breaker tripped

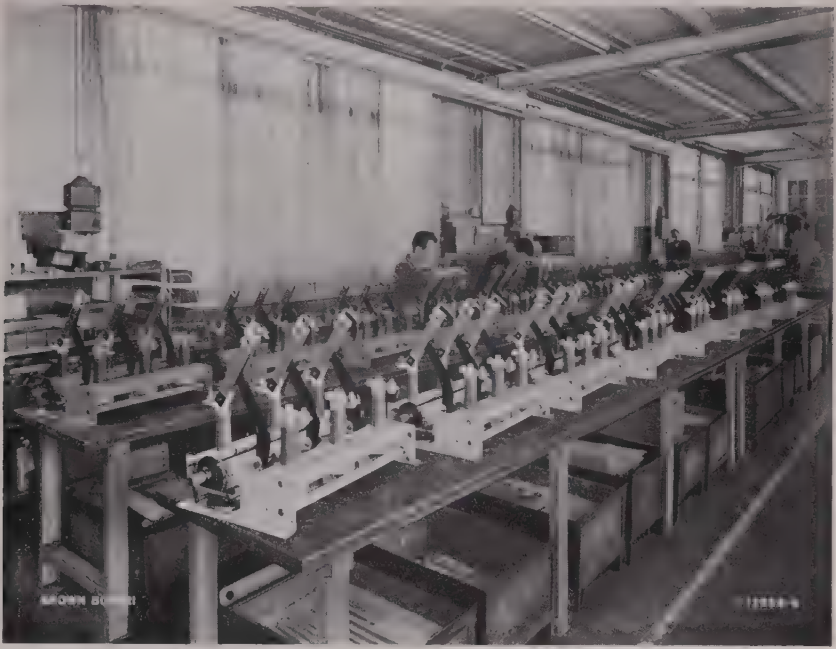

Fig. 66. – Assembly bay for on-load isolators in the switchgear factory

operated at no-load, this number of operations may be raised to 10 000.

4. Isolators

The heavy-current isolators type ADG are now only made as single-pole switches. With the aid of coupling elements these can be combined to form double- or triple-pole isolators, or double-break isolators. Thus interesting combinations are available to suit the requirements of individual customers. An example is a double-break isolator for a peak making current of 350 kA, with a rated current of 10 kA, supplied to the Swedish State Power Board (see Fig. 67).

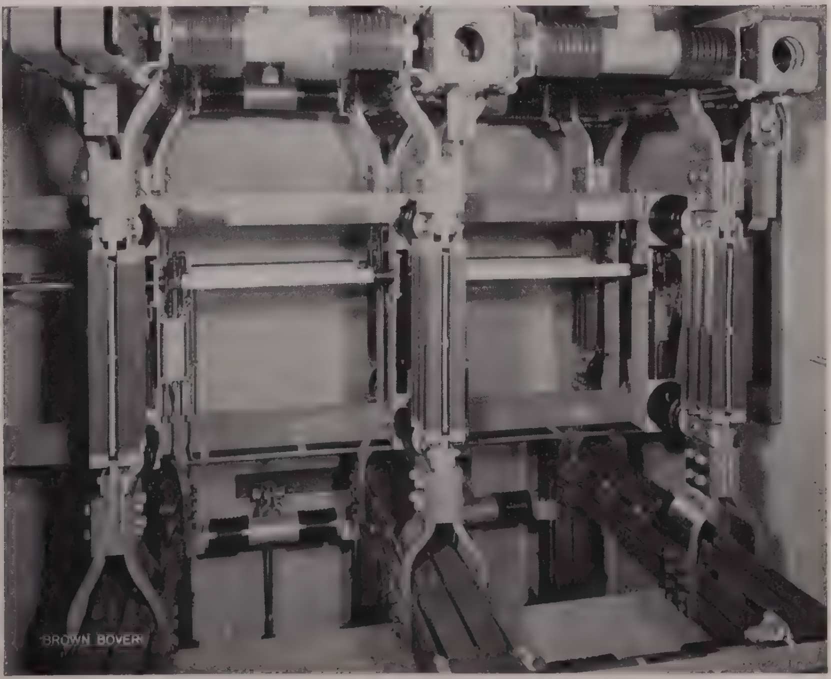

Fig. 67. – Double-break isolator rated 20 kV, 10 000 A, in a power station of the Swedish State Power Board

e introduction of the single-column isolators for tdoor installations with 245 and 420 kV, and current ratings of 2000 A, has resulted in the receipt of some important orders from home and foreign customers. The Kraftwerke Vorderrhein AG., for instance, have ordered 16 triple-pole units for 245 kV and eight for 420 kV. Fig. 68 shows a 420-kV isolator of this type in the closed position.

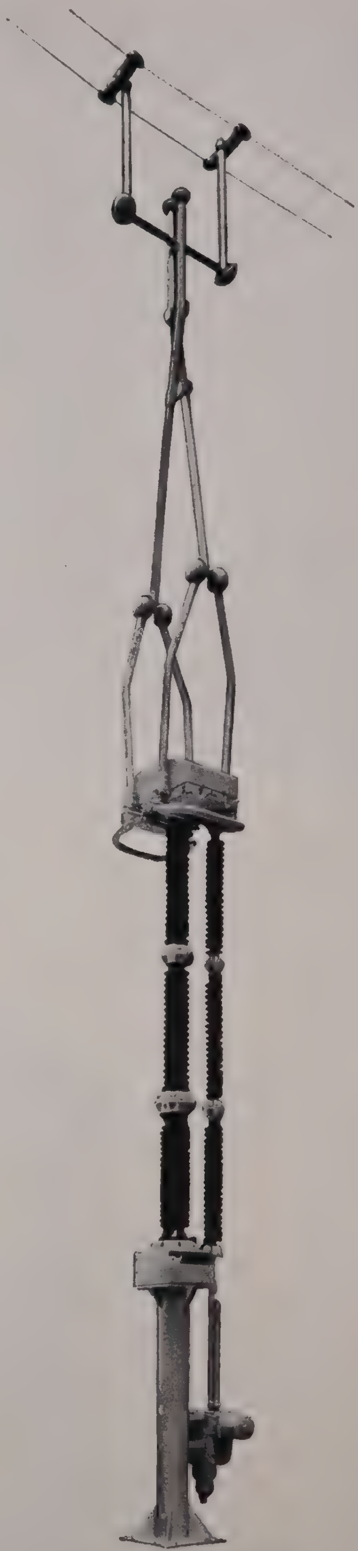

Fig. 68. – Outdoor single-column isolator rated 420 kV, 2000 A, in the closed position

5. *Metalclad Switchgear*

5.1 With airblast breakers

Just about a year ago, the first two machine sets of the largest hydro-electric generating station in Africa —Kariba in S. Rhodesia—were taken into service. The first building phase of this monster project covers six generators, each with a rated output of 111 MVA at a service voltage of 18 kV. The British consulting engineers decided to employ Brown Boveri airblast breakers rated 20 kV and 4000 A as generator breakers. These units have a breaking capacity of 2000 MVA. For the station transformers similar breakers were specified, in this case having a rated current of 2500 A, also with a breaking capacity of 2000 MVA, and metalclad. The generator breakers, isolators and instrument transformers are fitted in the run of the connections between the generators and transformers, the circuit-breakers being accommodated in extremely small niches, enclosed on two sides with metal cladding. The final assembly of these units took place in the power station (Fig. 69). The breakers, isolators and instrument transformers for the station transformers are housed in metalclad units, over 4 m in length (Fig. 70).

The elements in all these panels are easily accessible for inspection and maintenance, as soon as the necessary action has been taken to make entry into the interior safe.

For the sake of completeness it may be mentioned that, in addition to the above metalclad switchgear, Brown Boveri also provided all the 18-kV busbars and connections for this large underground power plant, involving about 1500 m of rectangular copper tubing with over 1000 supporting insulators of moulded resin, designed for a shear strength of 8 t (Fig. 71):

Close to the harbour of Leghorn (Italy) a new thermal power station is at present being erected, the first phase of which visualizes a steam turboset

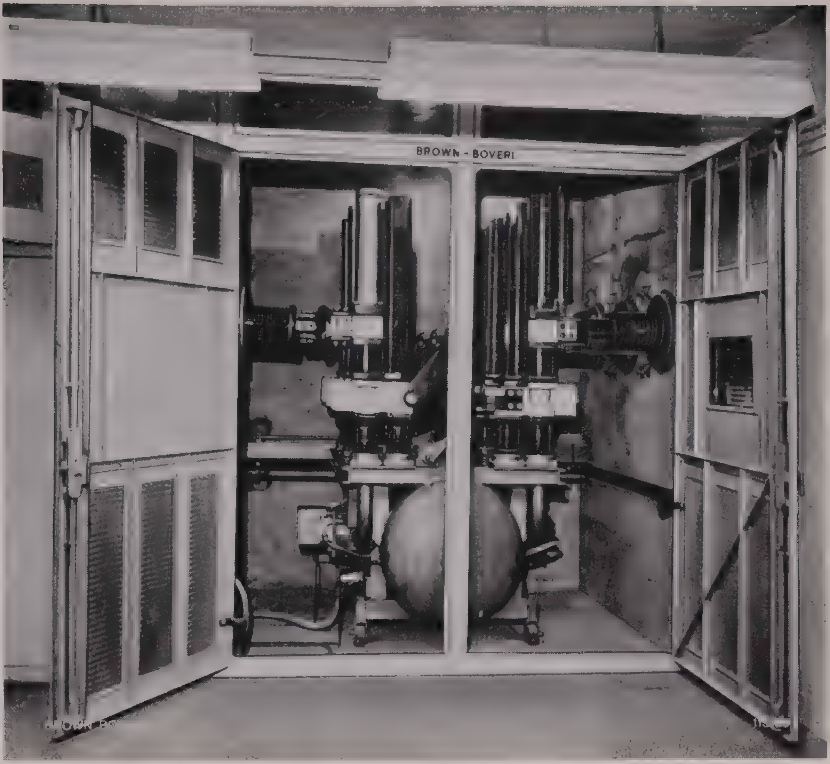

Fig. 69. – Generator breaker panel at Kariba power station, Southern Rhodesia, with an airblast breaker rated 20 kV, 4000 A for a breaking capacity of 2000 MVA

The breaker is mounted in a niche in the run of the generator connections, occupying a minimum of space although it is perfectly accessible and completely enclosed.

with a terminal output of 206 MVA. The associated breaker, to comply with the stipulated breaking capacity of 2500 MVA at a service voltage of 16 kV and a rated current of 7500 A, is composed of three single-pole airblast breakers, each metalclad with aluminium partitions between. The break time of the combined breaker is 0·06 s. Up to a service current of 5500 A the unit is naturally cooled. By adding a fan to create a powerful forced-draught in the breaker compartments, the rated current can be raised to 7500 A. The airblast breakers and generator connections, the latter being designed on the isolated bus system, are dimensioned to withstand a peak short-circuit current of 250 kA.

Once more a gratifying number of orders have been received for drawout metalclad panels with airblast breakers, a line which has been popular for several years, with rated voltages of 10 and 20 kV, rated currents from 800 to 3000 A and breaking capacities up to 1000 MVA.

5.2 With magnetic circuit-breakers

A large number of drawout metalclad units containing magnetic circuit-breakers have been ordered for industrial installations and power stations in parts of the world having very different climatic conditions.

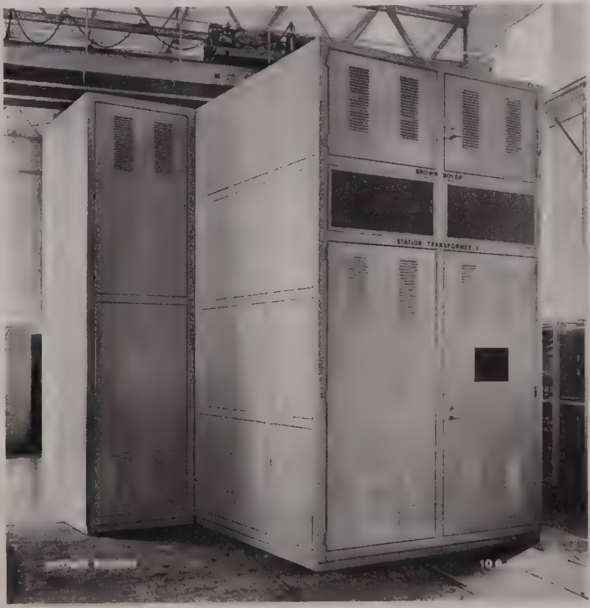

Fig. 70. – Breaker unit for a station service transformer at Kariba power station, Southern Rhodesia, with an airblast breaker rated 20 kV, 2500 A and 2000 MVA, together with pneumatically operated isolators and bushing-type current transformers

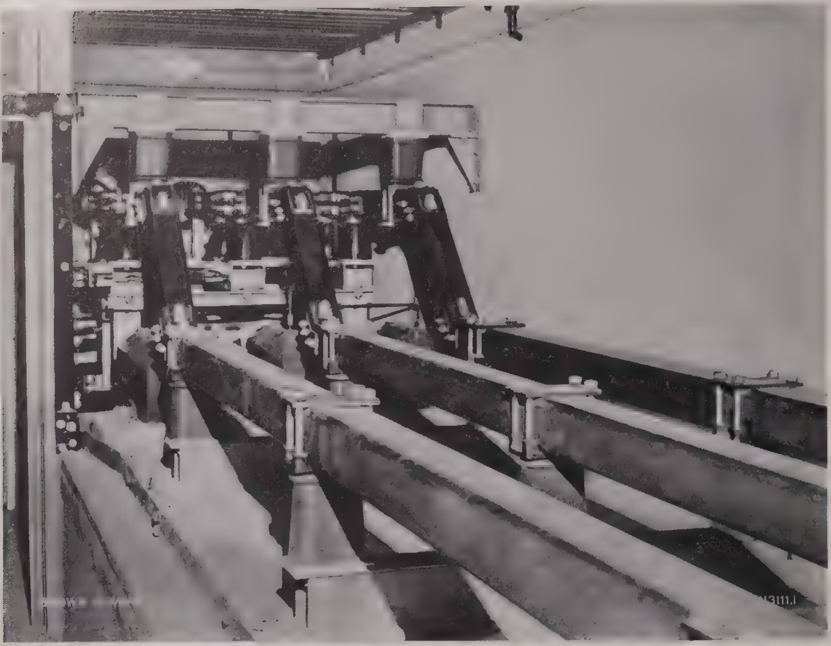

Fig. 71. – Connections between the generator breaker and busbars at Kariba power station, capable of withstanding very severe short-circuit forces

Service voltage 18 kV
Service current 3560 A

Some have been operating satisfactorily in clients' installations for some time.

A somewhat simplified version of the normal design,[2] and thus slightly cheaper, contains breakers for 3·6 kV employed at a service voltage of 2·2 kV, rated current 800 A, breaking capacity 75 MVA, and was ordered for an installation in India. The busbar insulation and some of the barriers between compartments inside the panels were omitted in these units (Fig. 72).

Development work has been continued on breakers and the associated metalclad units for rated voltages up to 17·5 kV, for which we shall be in a position to accept orders during the current year.

5.3 With low oil-volume breakers

In addition to metalclad units referred to in the last review of progress,[3] a simplified and therefore cheaper version of panels containing low oil-volume breakers has been brought out (Fig. 73). In them the arrangement of the breakers for rated voltages of 10 and 20 kV, 600 A rated current and breaking capacities of 280 to 400 MVA, has remained unchanged. They can be withdrawn from the service position to the disconnected position without opening the front door. However, the metal enclosure is confined to the outsides of the cells; barriers between compartments have been omitted. The busbars serving a complete installation are held at the walls between adjoining sections by means of slip-through insulators, the sections themselves being separated by a double thickness of sheet-metal. Of course, a mechanical interlock prevents the breaker from being inserted or withdrawn when closed. This kind of cell thus offers complete protection against inadvertent contact with live parts when the breaker is in the service or disconnected positions, plus the advantages of simplified erection, in that it is supplied completely assembled and, on arrival at its destination, only has to be placed in position and connected to the supply.

6. Relays and Protective Systems

6.1 Plug-in relays

The design programme of plug-in relays now covers all types of relays employed for supervisory or protective duties. At the same time as they are converted to the plug-in version, the relays will also be modified to incorporate improvements to the active parts which experience has proved necessary.

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[2] J. LATZKO: Metalclad switchgear with magnetic circuit-breakers for 3·6 and 7·2 kV. Brown Boveri Rev. 1959, Vol. 46, No. 9, p. 497–506.

[3] See Brown Boveri Rev. 1959, Vol. 46, No. 1/2; especially Table IV on p. 58.

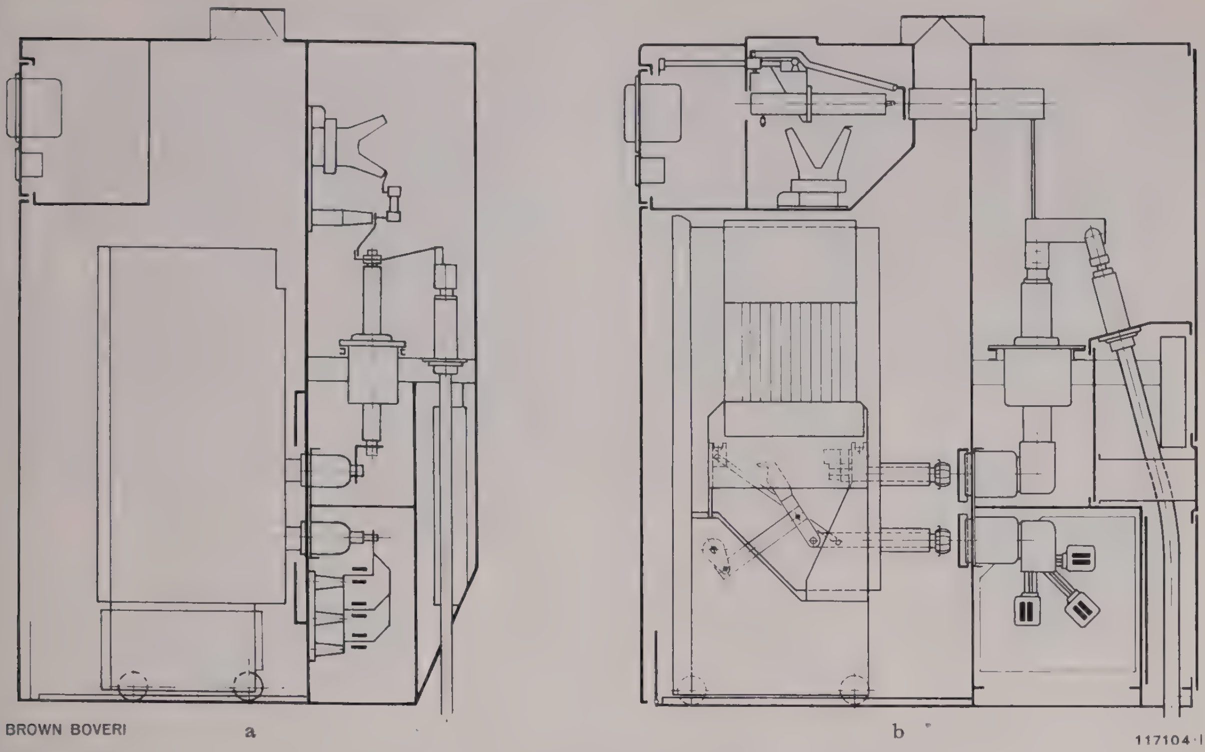


Fig. 72. – Sectional views of metalclad units with magnetic circuit-breakers

a: Simplified version with no busbar insulation, and a reduced number of barriers inside the panel. Voltage transformers accessible from the rear.

b: Standard panel with busbar insulation and sheet-metal barriers between all compartments. Voltage transformers accessible from the front.

The plug-in differential relay (on the extreme left of Fig. 74) has been adapted to the requirements of modern transformers by improving its inrush-proof qualities. This type of relay is also frequently employed for the protection of generators, and for similar duties.

The time-lag relay (second from left in Fig. 74) has also been modified to the plug-in version and has had its contact system adapted to meet modern requirements.

For several years the Company has produced an inverse-time overcurrent relay, particularly intended for protective duties in installations in which load surges are a feature of normal operation (Fig. 74, third relay from the left).

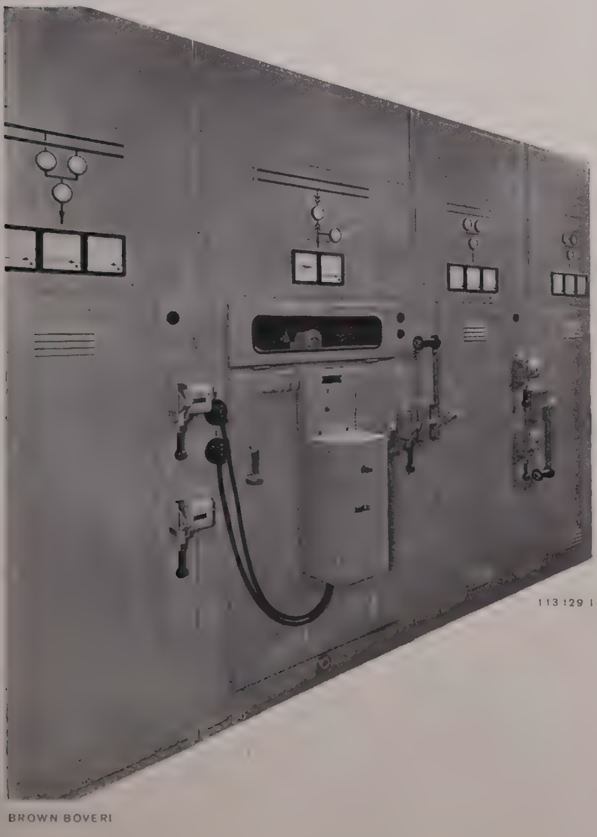


Fig. 73. – Switchgear installation with simplified drawout panels, containing duplicate busbars, low-oil-volume circuit-breakers for 10 kV, 600 A, 280 MVA, also 10-kV on-load isolators fitted with fuses and manual operating mechanism

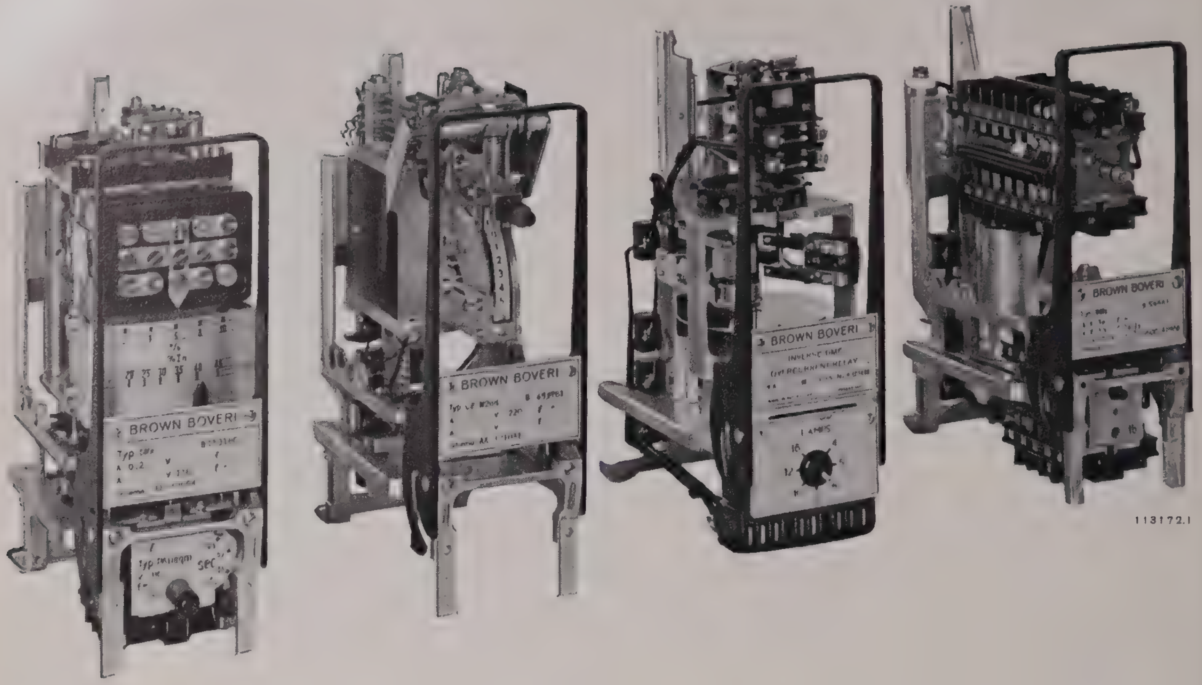


Fig. 74. – Measuring systems of various types of relays used for protective and supervisory duties

All these relays are accommodated in the same type of casing and are (from left to right): differential relay, time-lag relay, inverse-time relay, and a rough-service relay for use in railway vehicles. In view of the variety of uses, the differential relay is designed as a single-pole unit; polyphase applications require the appropriate number of individual elements.

The ability to plug the measuring system in and out offers great advantages when relays are employed on vehicles, such as locomotives. For traction purposes a special rough-service model has also been brought out, an example of which is to be seen on the extreme right of Fig. 74. A special advantage of the plug-in type of measuring system is that it can be easily and quickly replaced in the event of a breakdown, without any disconnection and rewiring being necessary. The design was made such that the dimensions of the casing remain unaffected, so that full advantage can still be taken of the facilities it provides.

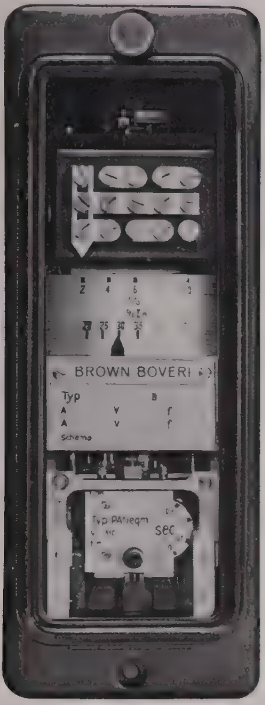
The plug-in measuring system is pushed in through an intermediate notched position, and only after this do the plug contacts touch, thereby applying the voltage or current to the relay itself. When the relay is withdrawn, the current transformer circuits are short-circuited by an overlapping shorting switch when the relay is removed from the disconnected position, thus preventing the transformer from being open-circuited. A relay inserted in its casing is illustrated in Fig. 75.

6.2 Small contactors

Apart from effecting certain improvements to the well-known contactors type P8 and P16, a new signal contactor type CV has been developed, intended primarily for use in control and signalling circuits. This contactor will normally be installed in pairs, corresponding to the nature of the commands, e.g. "On–Off".

A signal contactor can, of course, be used alone. The main points which were stressed in the design were compactness, low inherent consumption, and a reliable mechanical and visual signal. In conformity with the purpose for which it is intended, each unit is only equipped with two contacts for double interruption, thereby providing facilities for arrangement either as two make contacts, or as one make and one break contact. The contacts are capable of fulfilling the requirements of control and signalling circuits.

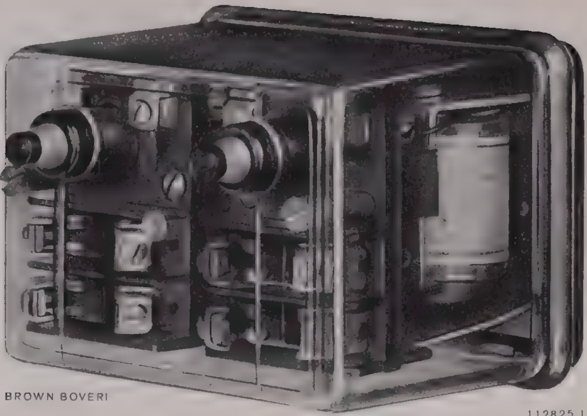
The signal contactor type CV is also ideal for use in conjunction with electronic control systems, in which not only the signal, but also the ability to



BROWN BOVERI 112426.1

Fig. 75. – Differential relay notched in the disconnected position in its casing

If the mechanism is withdrawn further, the current transformer connections are automatically short-circuited. In the disconnected position, which can only be overcome by operating the fixing lever, the mechanism of the relay can be safely changed.



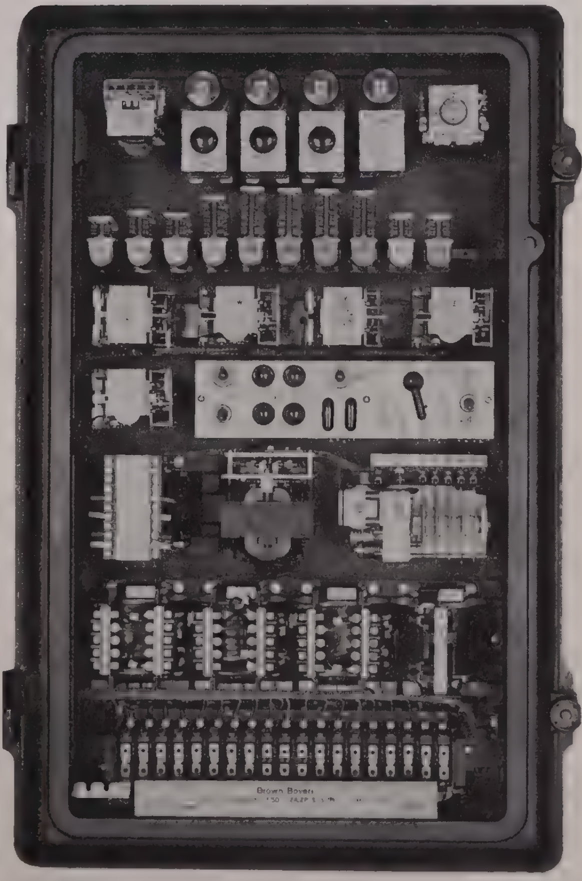
BROWN BOVERI 112825 I

Fig. 76. – Signal contactor type CV

This small contactor, shown here in the twin mounting, provides the contacts required for control or signalling, as well as a clearly visible signal button, but occupies a very small area. Illumination of the signal was dispensed with to retain the simplicity, and in order not to complicate the circuitry. If the button is pressed while the contactor is energized, this does not prevent the latter from operating correctly.

separate the potentials of the control and controlled circuits by the contacts is very important.

Fig. 76 shows the normal twin model equipped with make contacts. The signal is in the form of a stud, the tapered end of which is coloured bright red. Owing to the added complication in the circuitry which would be involved, illumination of the signal was dispensed with, thereby retaining the inherent simplicity. If the contactor is energized while a signal button is being pushed in, the completion of the movement is not affected.



BROWN BOVERI 113210.1

Fig. 77. – Distance relay panel type LZ 2 for use in high-voltage networks

This distance relay panel is employed for all the conventional forms of short-circuit protection, including rapid reclosure and carrier transfer. It can be fitted with an anti-hunting device, or with a sensitive summation current relay, thus superseding earlier models of distance relays, while occupying less space and containing more sensitive starting elements.

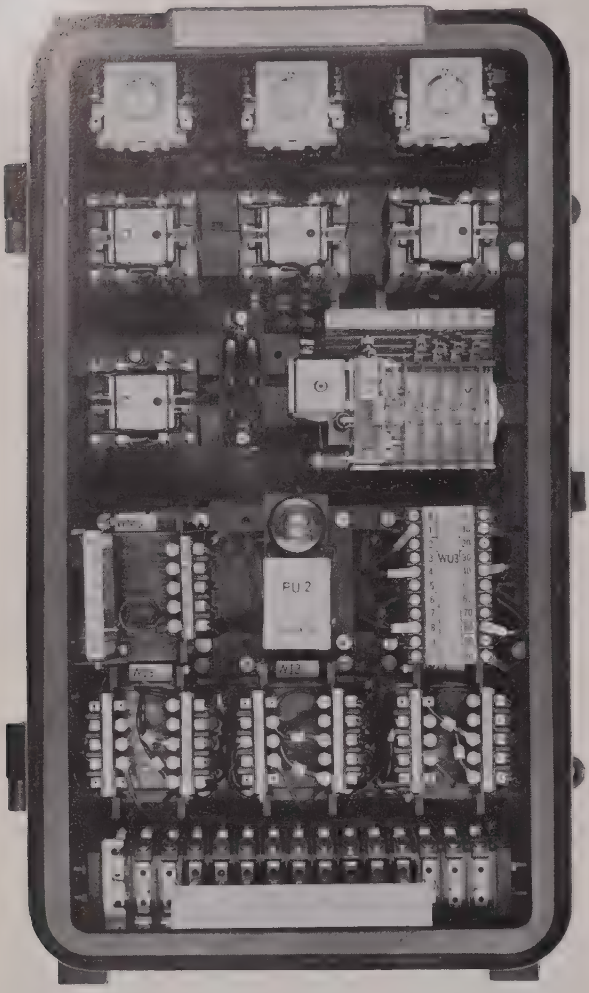


Fig. 78. – Distance relay type LI 3 for cable networks

This new distance relay employs starting elements responding to overcurrent and has a measuring circuit adapted to the impedance conditions of cable networks, containing a moving-coil relay as the switching element (denoted by PU 2 in the picture). The results of service trials have shown that this distance relay complies with a very wide range of requirements for the protection of cable networks.

6.3 Distance relays

A new distance relay has been developed for use in high-voltage networks, containing much simpler starting elements, having a more rapid response. The new relay can be used for all the tasks performed by the old distance relays, being suitable for all kinds of rapid reclosure, as well as for operation of the breaker at the far end of the line by carrier transfer. It can also be equipped with an anti-hunting device and, if specially requested, with a sensitive summation current relay. Its basic operating time is between 40 and 50 ms. The elements of the distance relay are housed in the standard casing which Brown Boveri have used for many years (Fig. 77).

For cable networks, in which the impedance conditions are quite different from those in overhead line systems, another new distance relay has been developed. The starting elements respond to an overcurrent, a new measuring system having been devised, possessing the sensitivity needed for the conditions in cable networks. This new development utilizes a measuring circuit in which the switching element is a moving-coil relay. Service trials have given very good results; the constructional layout is in keeping with those employed hitherto (Fig. 78).

6.4 Busbar protection

The interest in a selective, rapid and reliable form of short-circuit protection is steadily growing, not only for high-voltage busbars as focal points of interconnected power systems, but also in municipal and industrial distribution systems. The endeavour to do the utmost to preserve the dependability of the power supply is bound to lead ultimately to the erection of screened installations with barriers between individual feeders, or even phases, as well as transverse barriers between the compartments containing the busbars, isolators, circuit-breakers and instrument transformers, or to the provision of a really rapid, selective system of busbar protection.

It has been repeatedly proved that the Brown Boveri system of busbar protection employing product relays possesses the required properties; its operating time is of the order of 50–60 ms. It can be adapted to complicated multiple busbar systems without any change in the current transformer secondary circuits, so as to function selectively regardless of the connection of the installation.

Recently a number of busbar protection systems have been taken into service in power plants and substations; others are being erected. Particularly instructive is the equipment supplied to a municipal 10-kV substation with duplicate busbars and longitudinal isolators, coupling breaker, auxiliary section and 17 outgoing feeders. Since all barriers which were not absolutely necessary were omitted, having regard to the busbar protection, a very neat layout was obtained, as can be seen in Fig. 79. The resultant

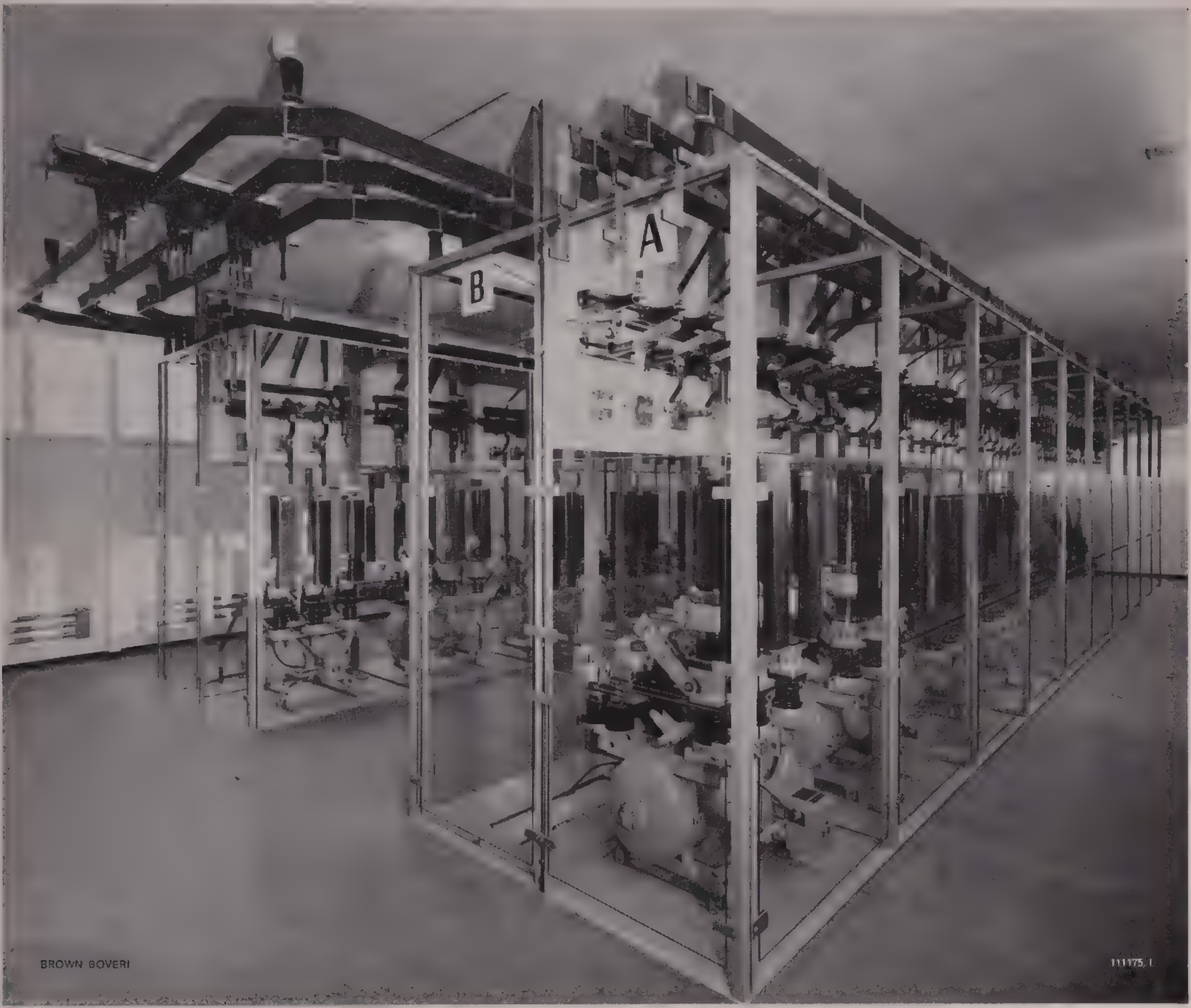


Fig. 79. – Protective gear for a 10-kV installation with duplicate busbars

The employment of this quick-acting system of busbar protection produces a neat, compact layout and dispenses with safety measures such as barriers between the busbar and breaker compartments and between the various feeders.

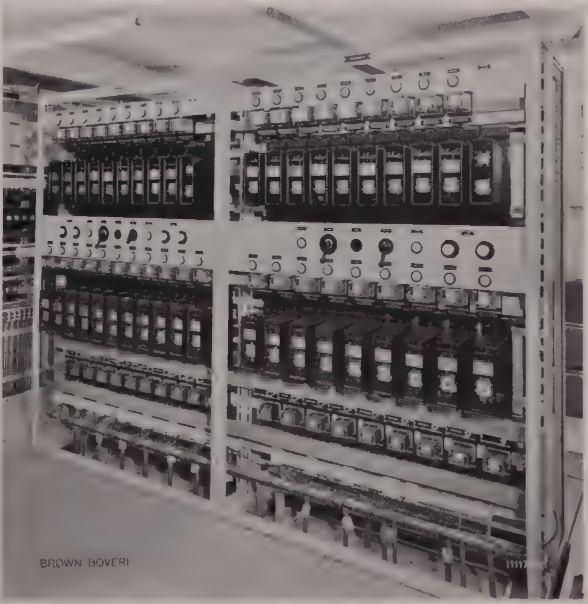


Fig. 80. – Busbar protective gear with testing and supervisory equipment

It functions without having the current transformer circuits changed, is selective and has an operating time of 50–60 ms. On the left is the equipment for the duplicate busbar system, as shown in Fig. 79; on the right, an independent system protecting the auxiliary busbars.

[illegible] in space and building work more than out[illegible]hs the cost of the protective gear. Fig. 80 depicts the latter, with its testing and supervisory equipment, which allow a full test to be carried out under operating conditions. On the left is the equipment for the duplicate busbar system, while on the right is a completely independent system protecting the auxiliary busbars. A second installation for the same client, but about 50% larger, with the same busbar arrangement in an existing building could not have afforded sufficient safety by constructional measures; complete reliability could only be assured by employing the system of busbar protection.

B. Instrument Transformers

1. Indoor Instrument Transformers

The manufacturing programme of our instrument transformers has been systematically augmented. The high-capacity auxiliary transformers mentioned in the last review of progress have been supplemented by smaller types, suitable for use either as auxiliary current transformers for adapting the current in the secondary circuit of the main current transformers, or as busbar, slipover or surrounding transformers (Fig. 81).

The invariable moulded-resin current transformers, which to begin with were only available for a maximum voltage of 12 kV, have since been augmented

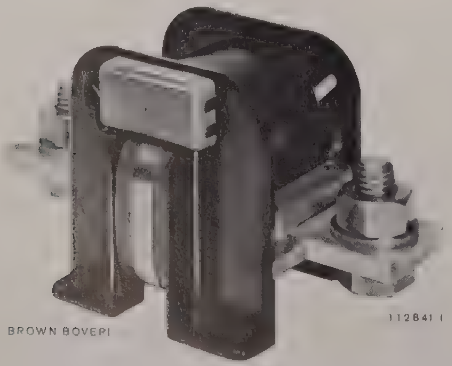


Fig. 81. – Busbar current transformer for indoor installations, with sealable terminal cover

Max. service voltage 1100 V, tested at 4 kV, 50 c/s; rated ratio 1000/5 A, rating 120 VA, class 3.

The coil assembly supports the entire unit and holds the core and connections in position.

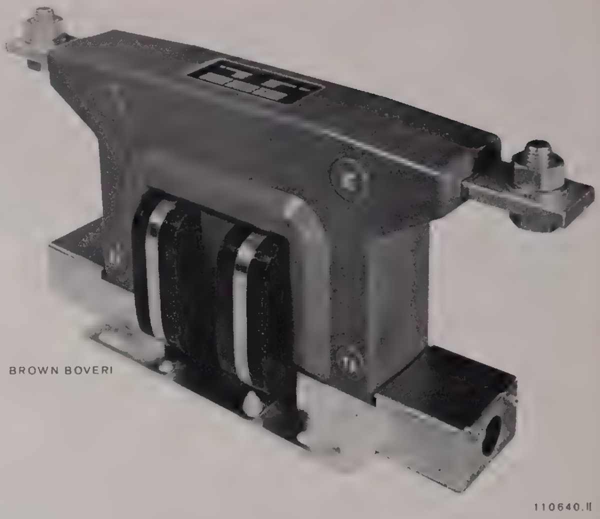


Fig. 82. – Insulator-type moulded resin current transformer

Max. service voltage 12 kV, rated ratio 200/5/5 A

Rating: core 1: 20 VA, class 0·5
core 2: 60 VA, class 3
Thermal short-time current 18 kA
Mechanical short-time current 90 kA (peak)

Owing to its elongated shape, the unit is quite narrow.

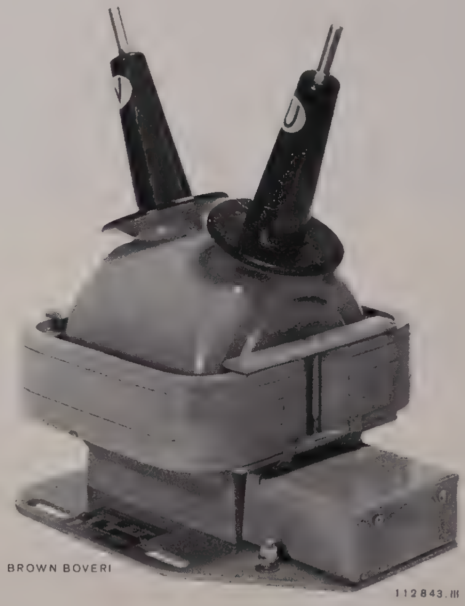


Fig. 83. – Single-phase moulded resin voltage transformer

Insulation class 17·5
Test voltage (one minute) 45 kV
Impulse withstand voltage 95 kV
Rated ratio 15 000/100 V, 50 c/s
Rating 60 VA in class 0·5
Max. burden rating 300 VA

The moulded resin body is surrounded by the continuous-strip core.

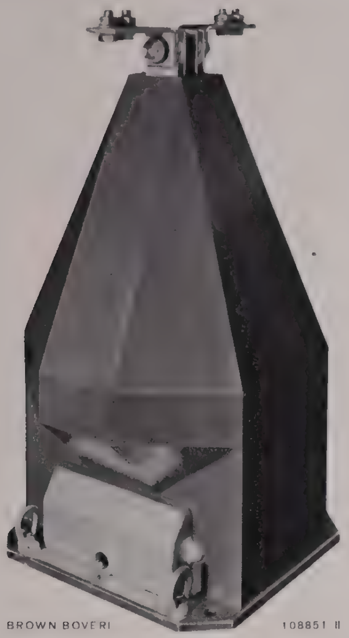


Fig. 84. – Insulator-type moulded resin current transformer

Max. service voltage 72·5 kV, 50 c/s
Test voltage (one minute) 140 kV
Impulse withstand voltage 325 kV
Ratio 600–300–150/5/5/5 A
Rating: core 1: 100 VA, class 0·5
core 2: 100 VA, class 0·5
core 3: 55 VA, class S 20
Thermal short-time current 60–30 kA
Mechanical short-time current 210–120 kA (peak)

The primary connections can be changed in the ratio 1:2, likewise the secondary; provision is made for conduit entry of the secondary leads.

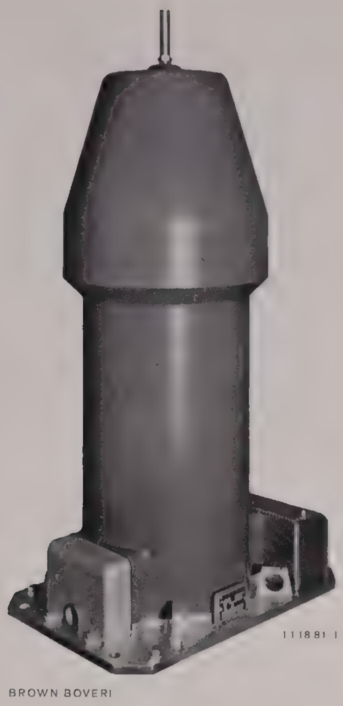


Fig. 85. – Single-phase moulded resin insulator-type voltage transformer

Max. service voltage 72·5 kV, 50 c/s
Test voltage (one minute) 140 kV
Impulse withstand voltage 325 kV
Rating 250 VA, class 0·5
Maximum capacity 1000 VA

The vertical design results in a very small base area being occupied.

by units for maximum voltages of 7·2 and 17·5 kV, with two cores as shown in Fig. 82. Owing to their small width, they are ideal for incorporation in metalclad switchgear panels. They can also withstand very heavy short-circuit currents; for instance a current transformer of this type, having a ratio of 20/5 A and a rating of 25 VA in class 3, can withstand a mechanical short-time current of 90 kA, or 4500 times the rated current, and a thermal short-time current of 18 kA r.m.s., or 900 times the rated value. A series of fully insulated moulded resin voltage transformers has also been developed for maximum service voltages of 3·6, 12 and 17·5 kV (Fig. 83).

The moulded resin range of instrument transformers has also been extended upwards and now covers the entire range of voltages up to 72·5 kV. Fig. 84 shows an insulator-type current transformer for indoor installations with a maximum service voltage of 72·5 kV and a rated ratio of 600–300–150/5/5/5 A. The corresponding voltage transformers are also designed as a vertical pillar, thus taking up a minimum of space (Fig. 85).

The fact that these instrument transformers are completely dry made it necessary for the special dielectric problems encountered in the design of units for 72·5 kV to be studied with great care, as a result of which considerable progress was made. The voltage at which they start to produce radio interference was raised to very high values. A large number of these units have already been delivered.

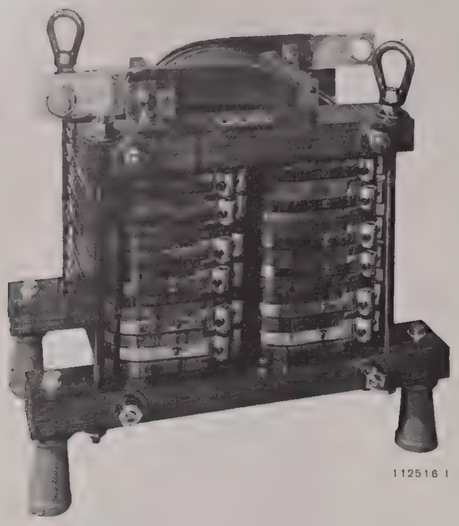


Fig. 86. – Stabilizing choke

Rated current 600 A
Test voltage to earth 7 kV

The elementary strip-wound and cut cores are held together by a pair of strong straps, the entire choke being compressed by drawbolts and supported by insulators.

The design principles on which these transformers are based have also proved fruitful as regards the accessories for rectifiers. A number of new designs with heavy-current windings have been brought out, including pulse transformers, reverse-current transformers and stabilizing chokes. Fig. 86 shows a stabilizing choke rated 600 A.

2. *Outdoor Instrument Transformers*

During the course of 1959 and 1960 many orders were received from all over the world for instrument transformers for voltages up to 420 kV. This proves that Brown Boveri designs are able to hold their own against international competition.

An example is given by the current transformers rated 275 kV, for a maximum service voltage of 300 kV, supplied to the Electricity Supply Commission (ESCOM) in South Africa and installed at Highveld (Fig. 87). A feature of these transformers is that they have four amply dimensioned cores and

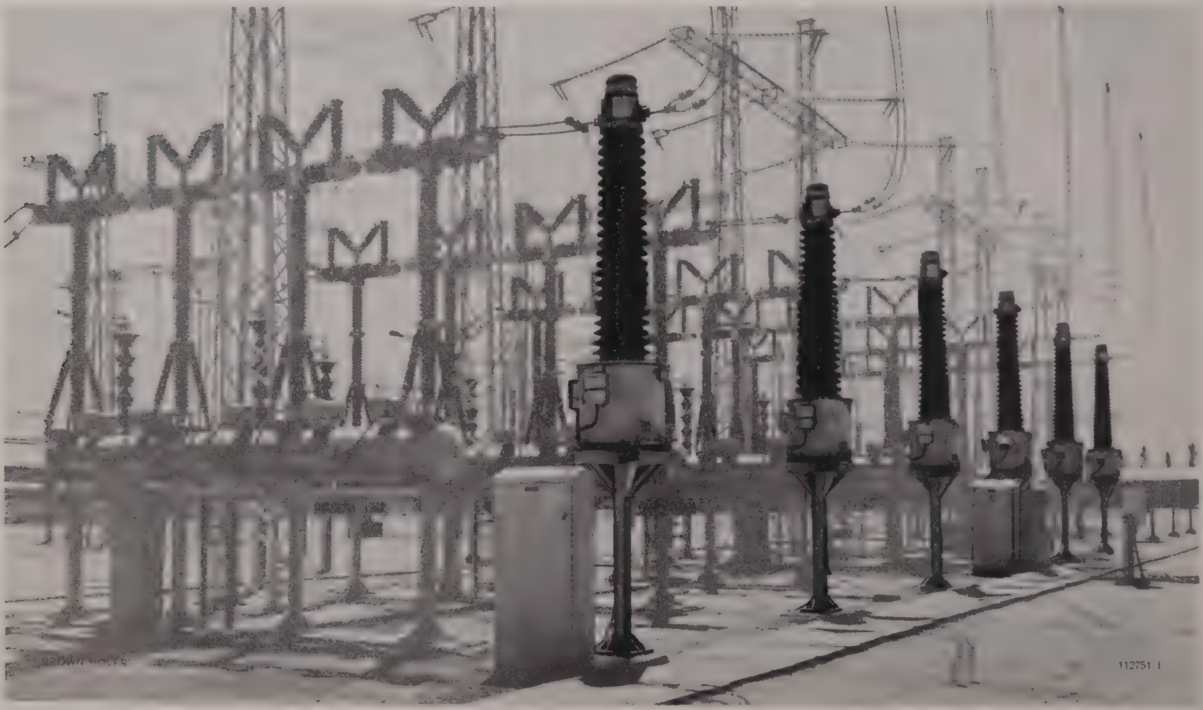


Fig. 87. Current transformers for 275 kV installed at Highveld power station of the Electricity Supply Commission, South Africa

$\frac{1200/800/200}{5/5} + \frac{500}{1/1}$ A, 50 c/s Test voltage (one minute) 490 kV Impulse withstand voltage 1050 kV

The four secondary cores, which have to fulfil special conditions, produce a tank with rather a large volume. The creepage distance on the surface of the insulators is also extended.

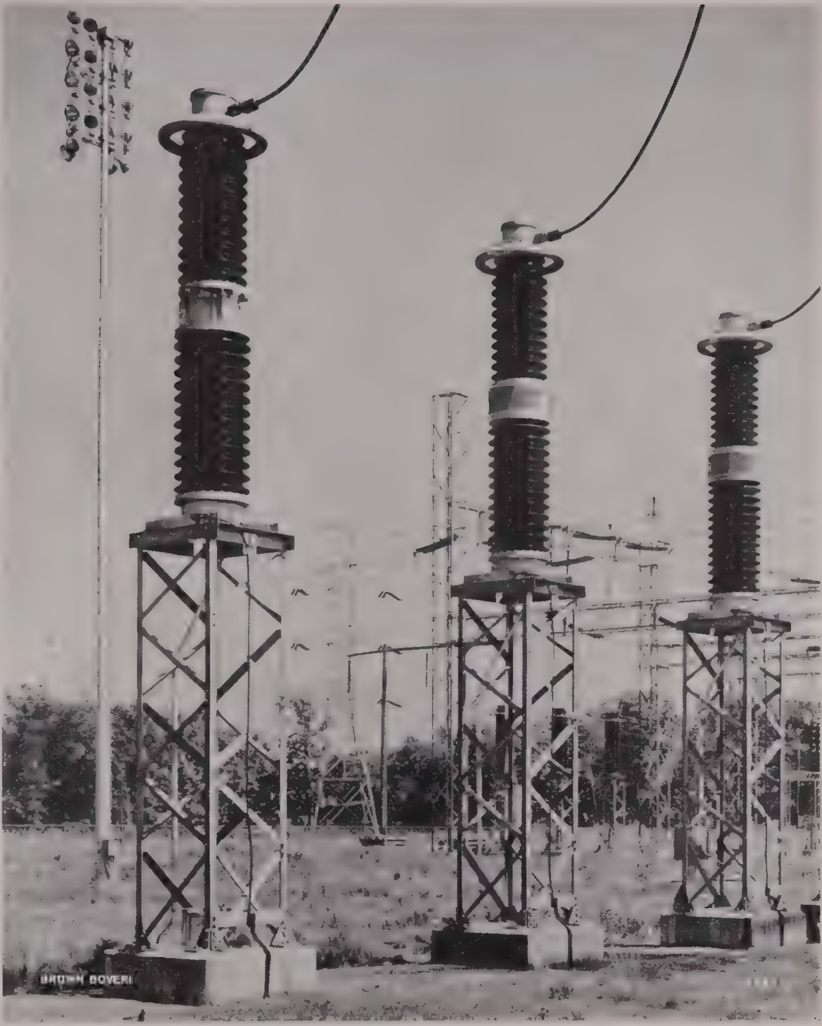


Fig. 88. – Single-phase voltage transformers installed at Bout de l'Ile substation of the Quebec Hydro-Electric Commission, Canada

Rated ratio $300\,000/\sqrt{3} : 120/\sqrt{3}$ V
60 c/s, 400 VA, class 0·3

Test voltage (one minute) 690 kV
Impulse withstand voltage 1550 kV

The upper half of the two-part transformer is simply placed on top of the lower half. Only three connections have to be made in the small box in the middle (see the unit on the left of the picture, the enclosure of which has been removed). The oil-baths of the two halves are completely independent of each other and thus involve no interconnections. When erection is finished, the casing round the middle has to be fitted (see the two units on the right).

extra-long creepage distances on the surface of their insulators, on account of the misty atmosphere.

In the sphere of voltage transformers noteworthy cascade arrangements have been developed which can be employed with advantage on extra-high voltages. Apart from the electrical advantages of this arrangement at high voltages, as described in an article dealing with units for 345 kV,[4] the transport and erection are greatly simplified. The transformer can easily be despatched in two separate sections. On arrival at site, these have only to be placed one on top of the other and three connections made in a small box in the middle part (see Fig. 88, especially phase A on the left). Interconnections for the oil are unnecessary as each half has its own, completely independent oil-bath. The core of these units is bar-shaped. All new instrument transformers are hermetically sealed with a flexible bellows to allow for expansion of the oil. In this way maximum freedom from disturbances by external factors is assured.

C. Power Transformers

In the sphere of power transmission at 400 kV Brown Boveri have continued to provide equipment to various undertakings. Among these are the four single-phase three-winding transformers mentioned in the last review of progress, ordered by Imatran Voima Oy, Finland, built in Mannheim to designs drawn up in Baden. Fig. 89 shows one pole of this

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[4] H. Hartmann and B. Gänger: A new design of voltage transformers for extremely high voltages. Brown Boveri Rev. 1960, Vol. 47, No. 5/6, p. 306–20.

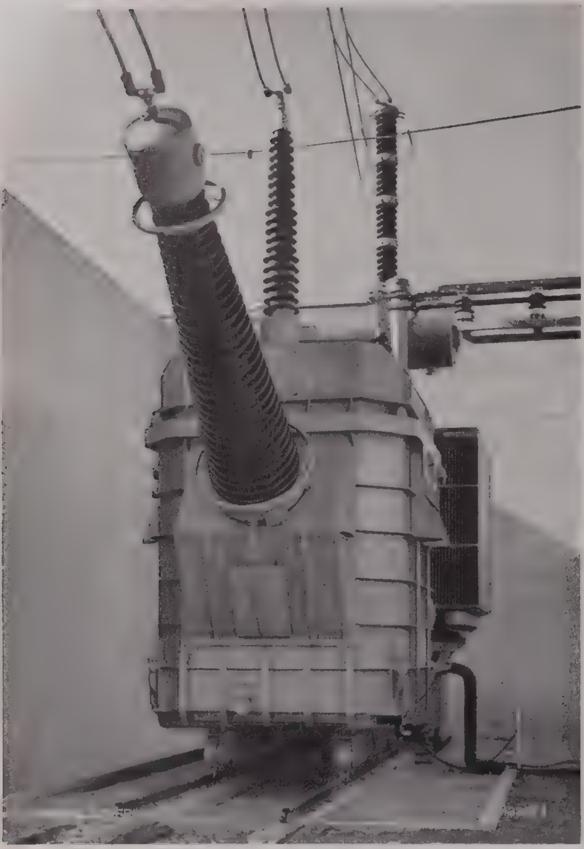

Fig. 89. – One of four single-phase autotransformers supplied to the Hyvinkää substation of Imatran Voima Oy in Finland, where they form a 420-MVA three-phase bank with one reserve unit

$$\text{Bank rating}\quad \frac{420}{\frac{420}{165}}\,\text{MVA},\quad \frac{380}{\frac{238}{20}}\,\text{kV},\quad \left(\frac{\perp}{\triangleleft}\right),\quad 50\ \text{c/s}$$

420-MVA bank installed. At the Swiss power station Sils im Domleschg (Grisons), owned by the Kraftwerke Hinterrhein AG., one three-phase bank rated 400 MVA has so far been taken into service; the remaining four single-phase units are almost ready for delivery. Until the transmission line is completed, the 400-kV winding of these transformers will be energized but not loaded. Fig. 90 shows this bank in the installation. The transport of these large units by a narrow-gauge railway with restricted load capacity on the bridges imposed severe limits for the engineering and design of these transformers (see also colour plate VIII).

The three 100-MVA banks of tap-changing transformers in the Creux de Chippis installation, Switzerland, have commenced operation and, as Fig. 91 shows, make an imposing row.

For the part of the new generating station at Göschenen, supplying the Swiss Federal Railways, Brown Boveri completed four 25-MVA single-phase transformers for a frequency of $16^2/_3$ c/s during 1960. As may be gathered from Fig. 92, these units were designed with two-limbed cores. The reason for this is not the high 50-c/s type rating of 75 MVA per unit, but the client's stipulation that the h.v. windings must be suitable for series or parallel connection.

From Canadian-Brazilian Services Ltd., an order was received covering six single-phase coupling transformers for the Terminal Norte substation in Brazil; they have a bank rating of 150 MVA and a transformation ratio of

$$\frac{220-210-200-190}{\sqrt{3}} : 88\ \text{kV}$$

at a service frequency of 60 c/s. One bank has already been delivered.

As regards the single-phase regulating autotransformers with a bank rating of 125 MVA, for the interconnection of 220 with 150-kV networks, which have almost become a standard product, twelve have been ordered by the North-East Swiss Power Co. for their Breite and Beznau substations, and three by the Bernese Power Co., for Bickigen. Of these, two banks have already left the works. This type of transformer has also found favour abroad, with the result that, in addition to the seven transformers for Coimbra substation of the Portuguese Companhia Nacional de Electricidade, four similar units have been ordered for the Vermoim substation of the same undertaking. The data of these units are:

$$\text{Single-phase;}\quad \frac{120/3}{\frac{120/3}{40/3}}\ \text{MVA};\qquad \frac{220/\sqrt{3}}{\frac{(135\text{–}180)/\sqrt{3}\ \text{kV}}{10}};$$

$$\left(\frac{\perp}{\triangleleft}\right);\quad 50\ \text{c/s}$$

For three-phase banks rated 50–60 MVA—mostly with on-load tap-changer control—a large number of the well-known radially laminated transformers have been ordered and, in some cases, delivered.

Within the period under review a number of respectable three-phase units have also been dealt with. Fig. 93, for example, depicts a regulated trans-

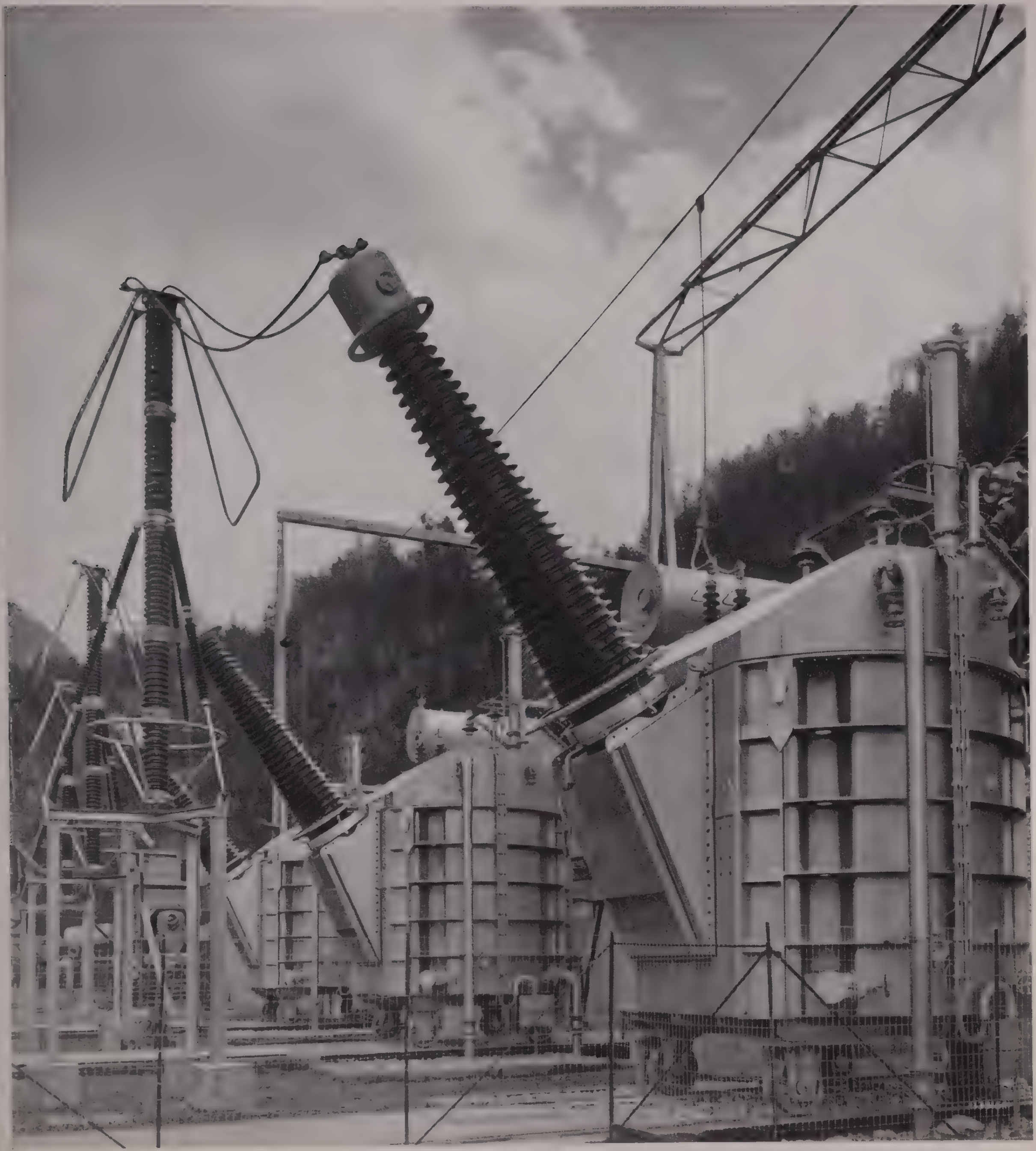

Fig. 90. – Seven single-phase auto-transformers forming two 400-MVA three-phase banks with a reserve unit, at the Swiss power station at Sils im Domleschg, owned by the Kraftwerke Hinterrhein AG.

$$\text{Bank rating}\quad \begin{array}{c}400\\ \hline 280\\ \hline 72{\cdot}5+72{\cdot}5\end{array}\ \text{MVA},\quad \begin{array}{c}420\,/\sqrt{3}\\ \hline (306\text{–}200{\cdot}8)\,/\sqrt{3}\\ \hline 10{\cdot}5,\ 10{\cdot}5\end{array}\ \text{kV},\quad \left(\frac{\perp}{\triangleleft}\right),\quad 50\ \text{c/s}$$

Since the outgoing 380-kV line was not complete at the time this photograph was taken, the corresponding terminals of the transformers are still disconnected.

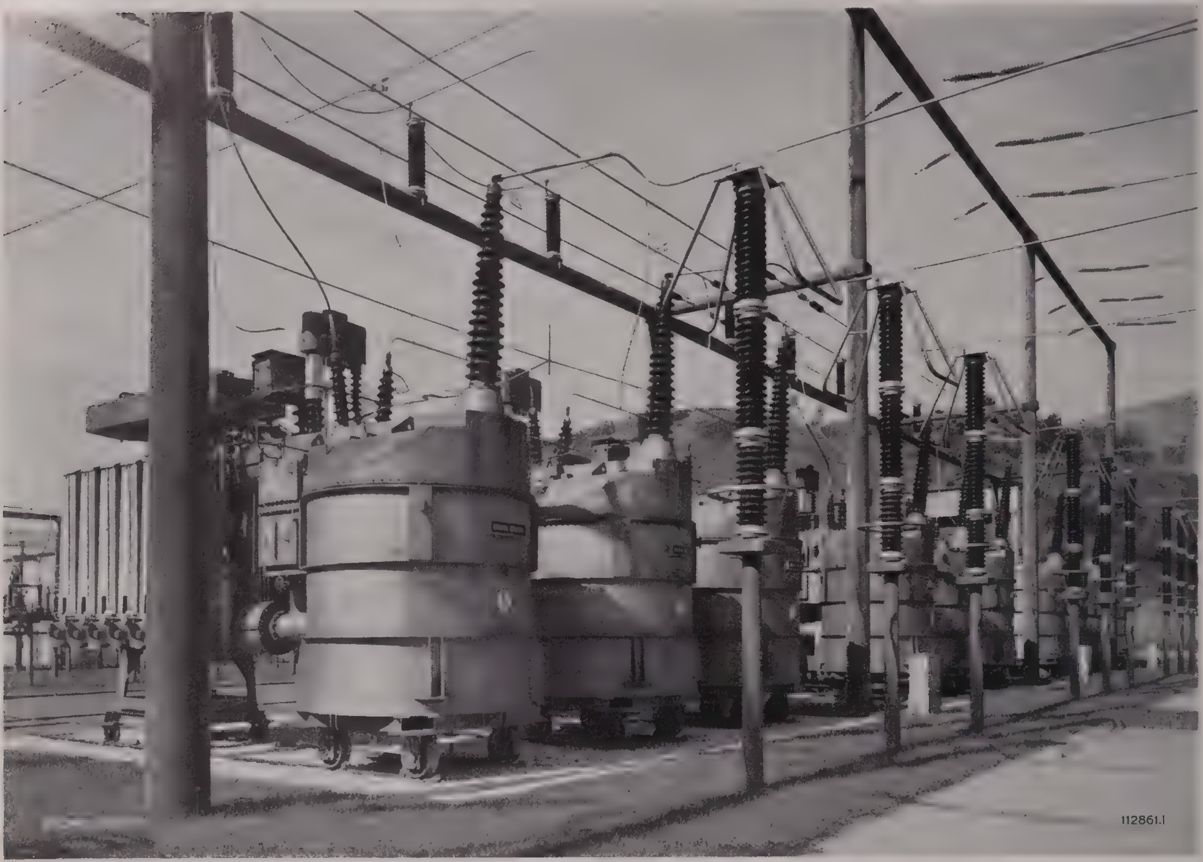

Fig. 91. – Ten single-phase transformers forming three three-phase banks with one reserve unit, installed in the Creux de Chippis substation of the Gougra Power Co., Siders, Switzerland

Bank rating 100 MVA, $\frac{70}{300\text{–}210}$ kV, $\left(\triangleleft\curlywedge\curlywedge\right)$, 50 c/s

former whose output can be raised from 50 MVA to 66·7 and 83·3 MVA, respectively, by fans switched in two stages. In addition to this unit is the group of four 100-MVA three-phase transformers shortly before leaving the works for delivery to the Tuscarora pumping station of the Power Authority of the State of New York. The other technical data of these transformers are:

(252 – 246 – 240 – 234 – 228)/13·2 kV; $\frac{\curlywedge}{\triangleleft}$; 60 c/s.

Also destined for the United States are three 70-MVA three-phase transformers, with the ratio 13·6/173·24–160·92 kV, 60 c/s, ordered for Wilson Dam power plant of the Tennessee Valley Authority.

In the field of locomotive transformers it is gratifying to be able to report on a repeat order for 24 transformers rated 4500 kVA with high-voltage control, ordered for C_0C_0 locomotives of the Swiss Federal Railways, as well as an order for five units of the same rating, ordered by the Berne–Lötschberg–Simplon Railway (BLS) for modernization of their Ae 6/8 locomotives.

Following the successful commissioning in 1960 of four single-phase shunt reactors in the form of a 24-MVA bank for 275 kV in the Port Augusta station of the Electricity Trust of South Australia (Fig. 94), an order was received from the Swedish State Power Board for a similar bank of reactors, this time with a rating of 150 MVA at a phase voltage of $226/\sqrt{3}$ kV. In these units the endeavours to reduce noise and vibration have proved very successful indeed.

With the introduction of cold-rolled laminations, it was only natural for the butted principle to be

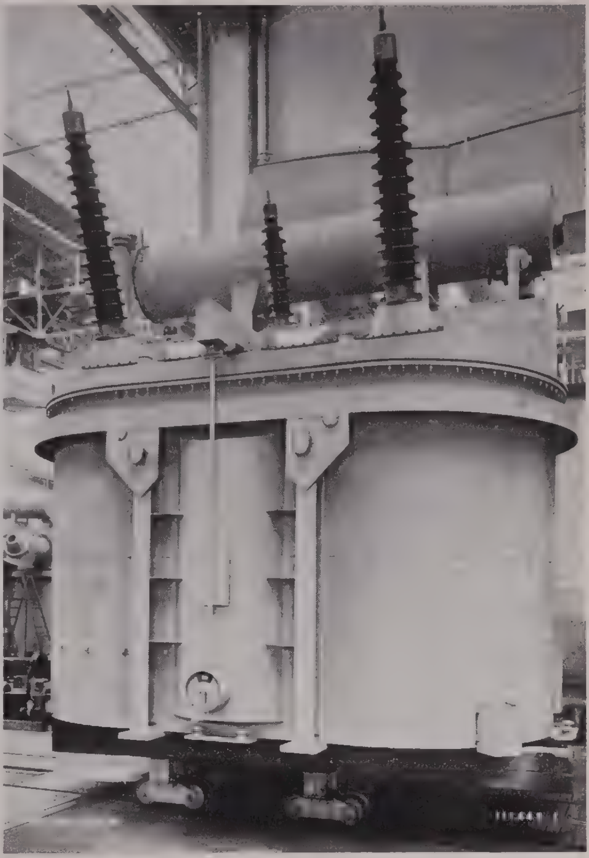

Fig. 92. – One of four single-phase transformers for the section of Göschenen power station which will supply power to the Swiss Federal Railways

$$25\ \text{MVA},\ \frac{13}{154\text{–}149\text{–}144}\ \text{kV, or}\ \frac{13}{77\text{–}74{\cdot}5\text{–}72}\ \text{kV}$$

Frequency 16 $^2/_3$ c/s

discarded and the interleaved design adopted, which has already proved very effective for small and medium transformers. Our designs have also been adapted to the peculiarities of these grain-orientated sheets, enabling us to make full use of their properties. Experience shows that an increasing number of customers, on comparing the two designs with hot and cold-rolled laminations, find the solution with the latter more interesting on account of the lower iron losses and decide in its favour, in spite of the higher price. It will not be long before hot-rolled laminations are only used for special purposes, e.g. locomotive transformers for 16 $^2/_3$ c/s and transformers which are only in service for brief periods.

In the range of distribution transformers with ratings from 200 to a few thousand kVA a new design

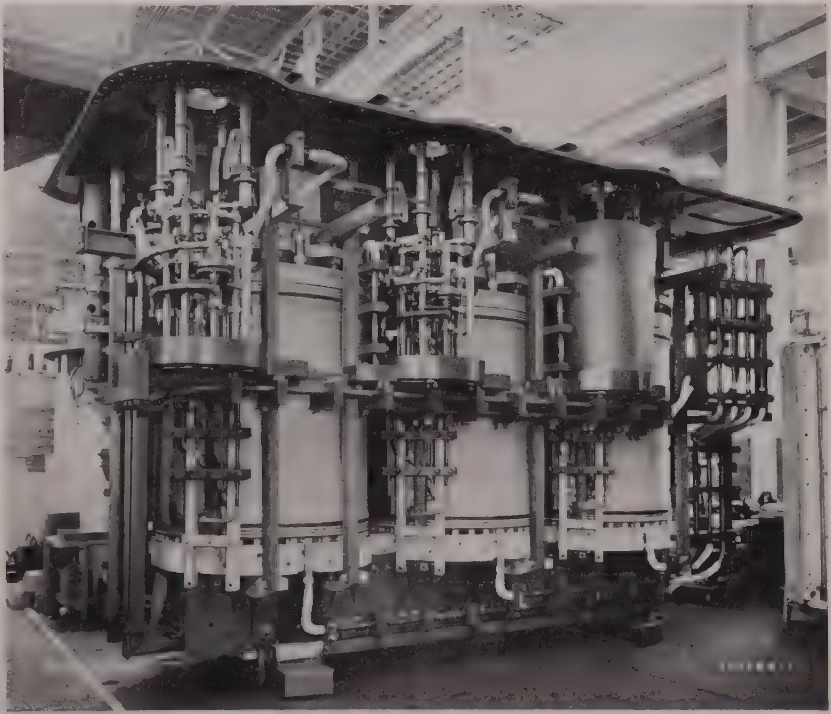

Fig. 93. – Three-phase oil-immersed transformer with tap-changer control for Fairmount substation of the Bonneville Power Administration, USA

50 / 66·7 / 83·3 MVA

$$\frac{115\text{–}103{\cdot}5}{70{\cdot}725\text{–}69\text{–}67{\cdot}275}\ \text{kV},\left(\frac{\triangle}{\curlywedge}\right),60\ \text{c/s}$$

with natural or two-stage forced cooling.

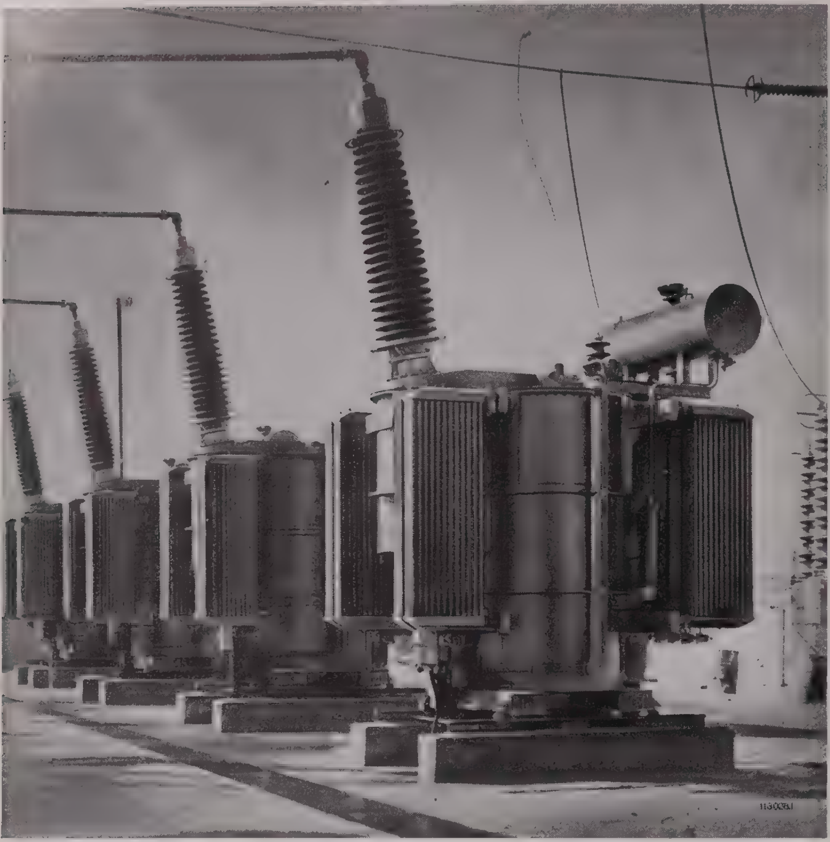

Fig. 94. – Four single-phase shunt reactors forming a three-phase bank with reserve unit at the Port Augusta B power station of the Electricity Trust of South Australia, Adelaide

Unit rating 24 / 3 MVA, 275 / $\sqrt{3}$ kV, (⅄), 50 c/s

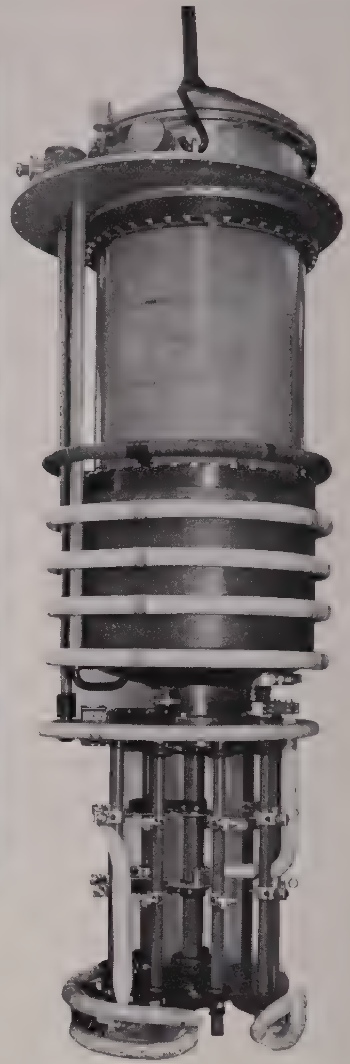

Fig. 95. – Built-in tap changer type LB, 245 kV, as fitted to the transformers for the Sils installation shown in Fig. 90

has been brought out, a feature of which is the complete symmetry of the phases, and which closely resembles the "temple" type devised by Charles E. Brown in the early days of the Company. The economic utilization of the active iron results in an appreciable reduction in the iron losses at a reasonable price.

Tap changers

For the 400-MVA regulating transformers for Sils a new built-in tap changer was developed and employed as phase switch at 245 kV. The switch is designed for a current of 1000 A and controls a range of ± 17 tappings with voltage steps up to 3 kV. Fig. 95 shows the tap changer ready for insertion.

With the development of this new tap changer, we are now in a position to fulfil the need, occasionally specified by customers, for a built-in tap changer. The major advantages of this new design are apparent when tap-changing transformers with built-on cable end-boxes are used, or where the space is very limited.

D. Rectifiers

During the period under review a decisive phase in the evolution of rectifier techniques was concluded. Semiconductor rectifiers have succeeded in proving their reliability and superiority in installations of the electro-chemical industry and have largely superseded the mercury-arc and mechanical rectifiers in

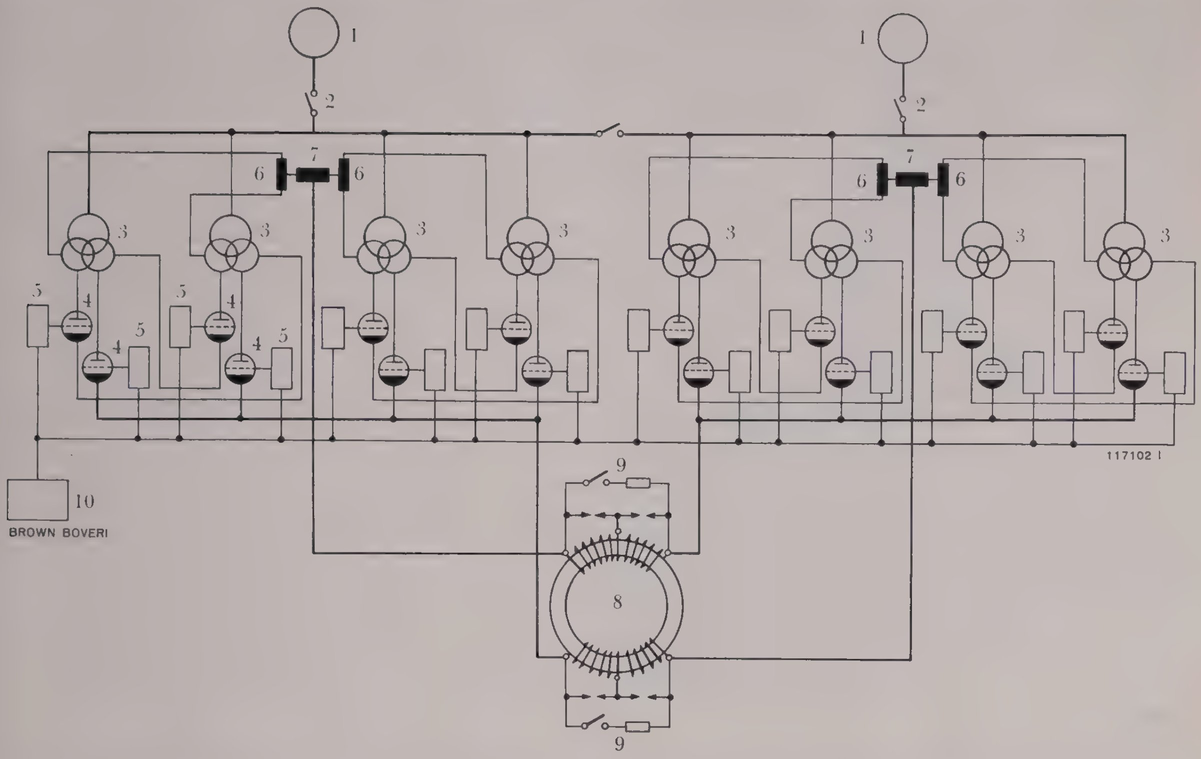

Fig. 96. – Circuit diagram of the 140-MW power supply equipment for the magnet of the 7-GeV proton synchrotron at Harwell, Britain

The rectifier section of this installation employs 96 single-anode tanks, each rated 800 A.

1 = Alternator
2 = Circuit-breaker
3 = Rectifier transformer (2 × 6-phase)
4 = Group of six single-phase rectifiers
5 = Grid control set
6 = Interphase transformer 300 c/s
7 = Interphase transformer 600 c/s
8 = Guide magnet
9 = Shorting switch
10 = Digital programming unit

this sphere. This major event characterizes the entire situation from the technical aspect and has had certain consequences which will now be described in detail.

1. Mercury-Arc Rectifiers

When the present series of mutators was being developed, the above trend was taken into account as we were fully aware of its repercussions. At the time every effort was made, and indeed, success was achieved in keeping the losses of even the largest single-anode types of rectifiers as low as possible, so that these units are still successfully employed in electrolytic plants. An excellent example is the large hydrogen electrolysis plant recently installed at Aswan in Egypt—the largest in the world at this time. Simultaneously the precision of control and the blocking capacity have been improved to such an extent that extremely difficult control tasks can be performed with the same tanks. Thus the necessary conditions were created to enable the mercury-arc rectifier to gain a hold on a field of application which it has since completely conquered, namely the instantaneous and lossless control of very powerful installations with reversible flow of energy.

We may be permitted to remark with some satisfaction that we have secured some of the most intricate and extensive contracts in a field of rectifier applications which will doubtless prove interesting and important in the future. Firstly there is the power supply equipment for the magnet of the 25-GeV proton synchrotron of the CERN in Geneva, the excellent performance of which helped the accelerator to be commissioned so quickly, an event which drew widespread attention. Another similar installation the 7-GeV proton synchroton of the Atomic rgy Establishment at Harwell in Britain, which is at present being erected. The circuit diagram of this large installation, for which the Company are supplying 96 single-anode mutators, the transformers, switchgear and control gear, is illustrated in Fig. 96. Very strict conditions were stipulated regarding the accuracy of control—particularly maintenance of the firing angle—but these are completely fulfilled by the transistorized grid control sets. A detail of great interest is the development of a digital programming unit to control the various stages of the acceleration process.

Noteworthy from the technical aspect of the control problems is an order received for equipment for feeding arc furnaces rated 7 kV and 3000 A in a European installation; this order was received on the recommendation of the Chemische Werke, Hüls, Germany, where a similar installation has given good results for many years.

The reliability of rectifier-fed drives, to which we have devoted special care for a long time, is nowadays undisputed. Other advantages are receiving increasing recognition, with the result that mutators have lately been installed in networks with quite limited capacities. These endeavours benefit from the preliminary work referred to in the last review of progress, in which full-scale trials were carried out over a period of two years with a rectifier-excited alternator rated 7000 kVA in a station of the Basle City Electricity Dept.[5] The outcome of these trials was that voltage drops caused by the heaviest surges could be corrected almost instantaneously, thus allowing mutators to be connected to relatively weak networks, even when severe load fluctuation is visualized. When rectifiers are used to excite synchronous capacitors, it becomes possible for the reactive power surges required to be generated on the spot, thereby assuring the supply of reactive power for drives running at reduced speed, in cases where this would otherwise have appeared problematical. A system of this kind was devised jointly by Brown Boveri, Mannheim, and the Röchlingsche Eisen- und Stahlwerke, Völklingen, Saar.

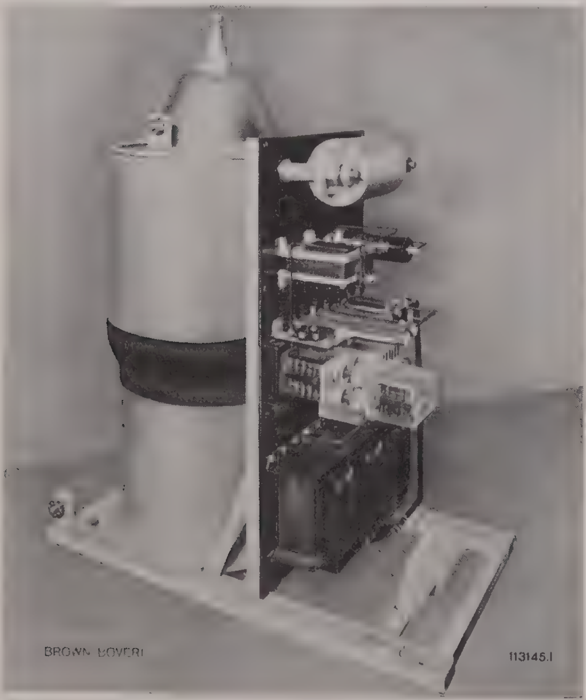

Fig. 97. – Packaged, pumpless, air-cooled single-anode rectifier for an average output of 100 A d.c.

The tank, with its auxiliaries for ignition, excitation and cooling, is built as a draw-out unit.

In consequence of the general trend in continuous rolling mills of changing over to individual, unit-connected drives, and to employ pumpless rectifiers for feeding them, Brown Boveri have delivered about 90 six-anode air-cooled mutators type KLg 36 during the period under review. Some of these were sent overseas for the first time, in particular to the continuous merchant mill of the Tata Iron & Steel Co., Jamshedpur, India, and to the wire mill of the South African Industrial Corp. in Pretoria.

Since mercury-arc rectifiers are being employed to a growing extent in small rolling mills, and for the auxiliary d.c. drives, the development of a new series of air-cooled single-anode tanks was commenced, in order to arrive at economical solutions even when only small powers are involved. The smallest type in this range is designed for an average current of 100 A and can be subjected to quite heavy load surges from cold. This pumpless single-anode mutator is made without any cathode insulation and is combined with its auxiliaries for ignition and excitation to form a compact assembly. These assemblies are accommodated in drawout units (Fig. 97) which can be inserted in a cabinet, the dimensions of which match those of the standardized switchgear cubicles, accommodation being provided for an air-cooled heat exchanger for the closed water circuit, if necessary, thereby rendering the mutator unaffected by the ambient temperature.

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[5] W. FREY and R. NOSER: CIGRE Report No. 127/1958.

To prove that mercury-arc rectifiers are still able to extend their classical fields of application the following examples may be quoted: 12 pumpless six-anode mutators type KLg 36 are rendering excellent service in substations of the Italian State Railways, some having been in operation for several years at a voltage of 3500 V. The same railway authority also has 14 sets of power supply equipment for dual-system motor-coaches, each containing six single-anode tanks. These motor-coaches cover an average distance of about 1000 km every day.

2. *Mechanical Rectifiers*

Whereas mercury-arc rectifiers reigned supreme in the field of electrolysis installations in the period up to 1950, the ten years which followed may be looked upon as the era of the mechanical (or contact) rectifier. True, the evolution of the contact rectifier dates back to 1936, but it was first marketed in 1950 and established a very high reputation within a few years. In 1951 a total of 12 such rectifiers with an average output of 1900 kW were delivered, by 1954 this number had grown to 21, each producing an average of 3500 kW, and in the period 1956 to 1957, which may be regarded as the most successful as far as sales were concerned, 29 units each producing 4100 kW were sold each year. The beginning of 1960 brought in orders for 12 more, each rated 4900 kW. All told, in the period from 1950 to 1960 a total of 152 units were delivered, with an aggregate output of about 570 000 kW, corresponding to a current output of 2 250 000 A d.c. Geographically these are spread throughout Europe and all continents of the earth. Practically speaking, they have all been in continuous operation ever since they were taken into service, the majority being employed at electrolysis plants generating chlorine; however, plants producing aluminium, copper, zinc and sodium are also included.

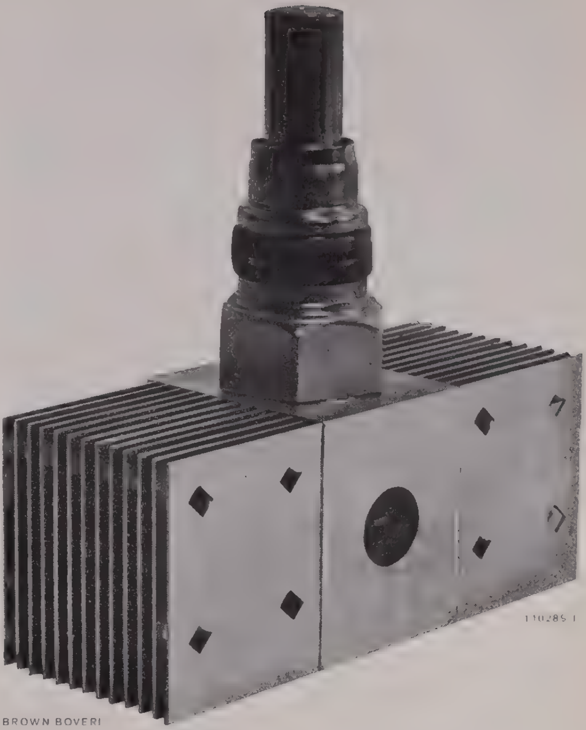

Fig. 98. – Silicon diode for a mean d.c. output of 200 A with forced-draught cooling and a peak inverse voltage of 600 V

In general the operational results are very satisfactory. The units are actually running for 97–98 % of the year and the contact life is between 5000 and 6000 hours. In some plants where the machines receive very careful attention and cooling is more effective, peak availability factors of 99 % are achieved, with contact life figures of over 10 000 hours. Overhauls to the gearing after 60 000 to 80 000 hours running have not shown any marked signs of wear, either to the roller bearings or to the ground cam-shafts.

With the commencement of a new decade, a new period has begun in the history of electrolysis rectifiers, brought about by the advent of the semiconductor rectifiers. Due to the advantages it offers as a static converter, the silicon rectifier will henceforth take the lead. But in its own decade the mechanical rectifier offered invaluable advantages for the electro-chemical industry. It remains as an example of purposeful research and collaboration, with which Brown Boveri held the lead in the world market.

3. *Semiconductor Rectifiers*

Already in 1955, when the mutator conference was held in Baden, reference was made to the development work being made in the field of semiconductors.

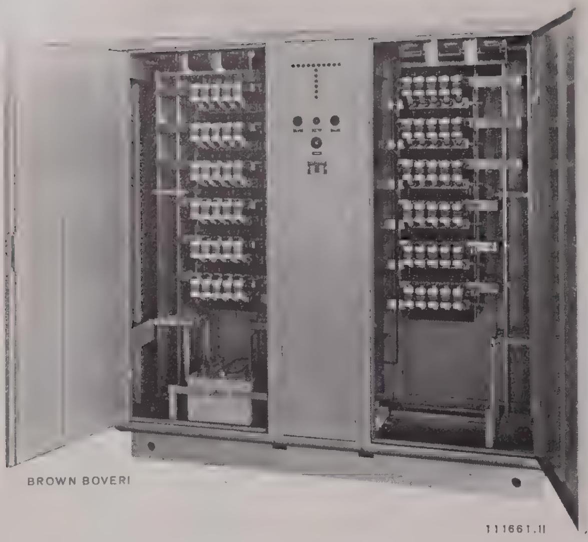

Fig. 99. – Cabinet containing semiconductor rectifier, front view with open doors

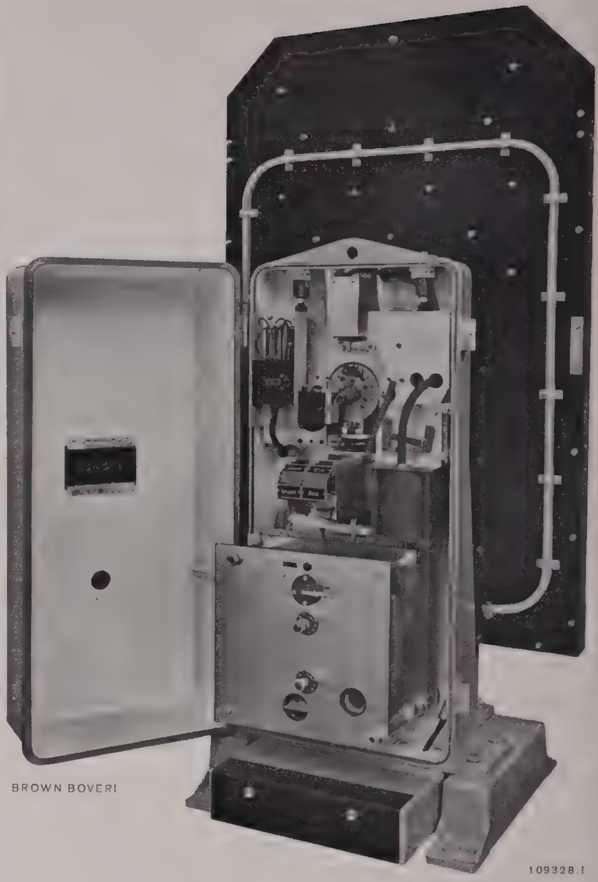

Fig. 100. – D.C. circuit-breaker for 10 kA at 1500 V showing the operating mechanism

This work was commenced on a broad basis and led first of all to the manufacture of germanium diodes, designed for an average d.c. output of 100 A and a rated peak inverse voltage of 100 V, with forced-draught cooling. A number of installations were equipped with these diodes which have been operating without disturbance since they were comissioned. The most notable of these is a rectifier rated 15 kA at 260 V, installed at the Badische Anilin- und Sodafabrik AG., Ludwigshafen, Germany.

Early in 1960 the production of silicon diodes for a mean d.c. output of 200 A with forced-draught cooling, for a rated PIV of 600 V, was commenced (Fig. 98). These diodes are able to convert much more power and are less sensitive to temperature, thus allowing the size of the installation to be considerably reduced. Severe tests having proved the reliability of silicon diodes. The first Brown Boveri rectifier unit employing them was taken into service in June 1960 at the Chippis plant of the Aluminium Industrie AG., producing 8·5 kA at 400 V. This was soon followed by a 1-kA, 825-V rectifier for a substation of the Oberrheinische Eisenbahngesellschaft, Mannheim, and an electrolysis rectifier in the aluminium works at Martigny in Switzerland; rating 36 kA at 350 V. Of the numerous other orders which have since been received, the following deserve special mention: Badische Anilin- und Sodafabrik AG. for 75 kA at 220 V; the Chemische Werke, Hüls, Germany, for 120 kA at 250 V; Nederlandsche Patent-en Kristal-Sodafabriek, Herten, Holland, rated 24 kA at 350 V; the Solvay works at Torrelavega, Spain, for 20 kA at 230 V; and the Attisholz cellulose factory, Switzerland, for 20 kA at 180 V.

The semiconductor diodes, with their cooling system, the fan connections and relevant protective gear, are fitted in cabinets (Fig. 99). In order to obtain an optimum performance from silicon diodes in a rectifier installation, a number of important conditions must be observed regarding the electrical circuit and its dimensions, the protection against overvoltage and overcurrent, and the cooling. The associated problems have been closely studied by the specialist departments, the results of which, and a description of the solutions chosen, will be dealt with in a special number of the Brown Boveri Review to be published later this year.

4. D.C. Circuit-Breakers

Modern chemical plants demand increasing quantities of d.c. energy, thereby imposing particularly severe requirements as regards the capacity, speed and reliability of the circuit-breakers. To meet such requirements a new circuit-breaker has been developed and is already rendering excellent service. It is designed for a rated current of 10 kA and for voltages up to 1500 V.

The maximum breaking current may be up to 80 kA; this means that, with a total time-lag of 5–7 ms, the breaker can handle any sort of short-circuit in the installation up to a maximum rate of rise of the current of 10 kA/ms, depending on the method of tripping. All elements concerned with the actuation and control of the breaker are housed in a dustproof casing and arranged in neat sub-assemblies. Among the more important installations equipped are:

Two breakers for 7 kA and 500 V, to the Vereinigte Aluminiumwerke, Grevenbroich, Germany

Two breakers for 7 kA and 1100 V for the Chemische Werke, Hüls, Germany

Five breakers for 3 kA and 750 V for the Von Moos' Ironworks, Lucerne, Switzerland.

Fig. 100 illustrates a d.c. circuit-breaker with the operating mechanism exposed.

E. Converters for System Interconnection

Not only the progressive electrification of railway routes, but also the steady increase in traffic causes the power consumption in traction networks to grow from year to year. This maintains the demand for converter sets for the flexible interconnection of single-phase traction networks with the national three-phase supply system. Brown Boveri have taken a close interest in this field for a long time. Two years ago a description was published of what was then the largest installation of this kind, namely Auhof converter station of the Austrian Federal Railways.[6] In the meantime this station has been extended to its full capacity of 60 MW. A third converter set has been installed, for which the Company again supplied the three-phase induction machine, the Scherbius control set and the accessory apparatus. The station may thus be considered the most powerful interconnection between two networks of different frequency. A view of the machine room is shown in Fig. 101. The three Scherbius sets are controlled by the method which has been employed in many similar installations and which may now be regarded as the classical method. It is based on the use of a double induction regulator controlling the active or reactive power of the induction machine.

At Araras in Brazil a small converter was taken into service in May 1960, providing the interconnection between two three-phase systems. This was necessitated by the fact that the supply to a certain factory was changed from 50 to 60 c/s and the management wanted to keep their existing drives in operation. Considerable fluctuation was anticipated in the 60-c/s supply from the very start, while stress was laid on the maintenance of good constancy in the 50-c/s system. The converter chosen consists of a four-pole synchronous generator rated 1000 kVA, 50 c/s, power factor 0·85, driven by an induction motor rated 950 kW, 60 c/s, for unity power factor. The speed of the motor is regulated to 1500 rev/min by a directly coupled Scherbius machine. As with the numerous other Scherbius control sets which have been built, the latter is shunt excited through a tapped transformer controlled through contactors by a frequency relay. This circuit arrangement, which is the normal one employed with industrial drives, requires very few accessories; there is no need for a frequency converter. Power factor correction by the Scherbius machine facilitates voltage regulation of the incoming line. A view of the installation is shown in Fig. 102.

A special number of the Brown Boveri Review issued in 1959 dealt with the successful commissioning of the power supply equipment provided for the proton-synchrotron at the CERN, Geneva.[7] In this

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[6] P. Rauhut: Auhof, the new converter station of the Austrian Federal Railways. Brown Boveri Rev. 1958, Vol. 45, No. 5, p. 195–211.

[7] See E. H. Ludwig, P. Rauhut, T. Wasserrab, R. Zwicky: The supply system for the magnet of the proton synchrotron of the CERN in Geneva. Brown Boveri Rev. 1959, Vol. 46, No. 6, p. 327–49.

P. Rauhut: The Scherbius control set for the CERN motor-generator. Brown Boveri Rev. 1959, Vol. 46, No. 6, p. 350-5.

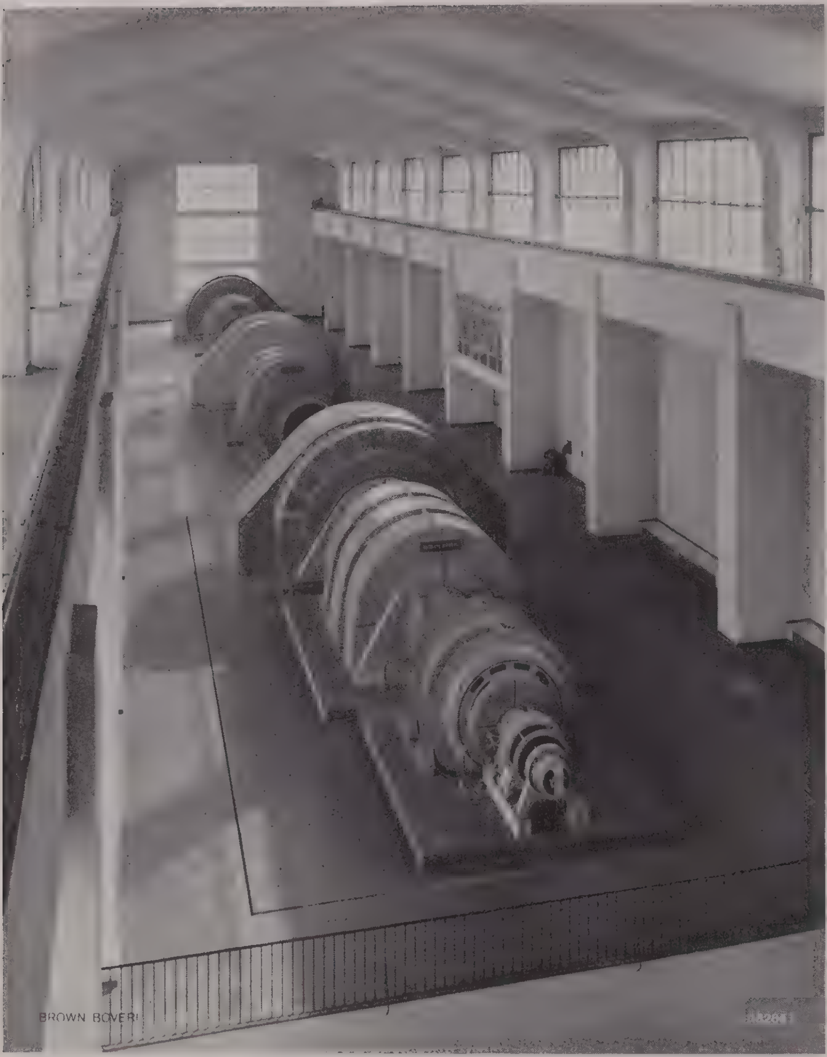

Fig. 101. – Three 20-MW converter sets in Auhof station near Vienna, where the single-phase 16⅔-c/s railway supply network is connected with the three-phase 50-c/s national grid

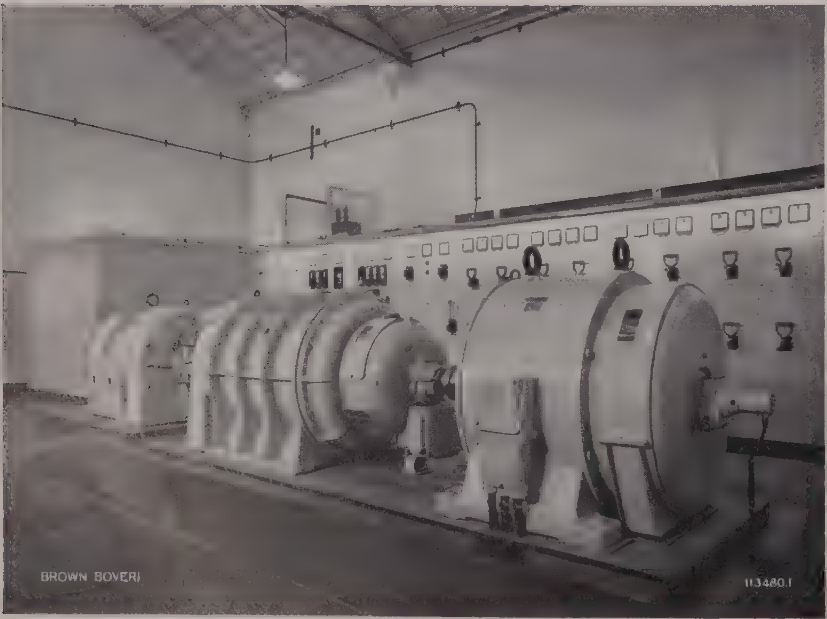

Fig. 102. – Converter set at Araras, Brazil, for connection between two three-phase networks operating at 60 and 50 c/s, respectively; rating 1000 kVA

The Scherbius machine is shunt excited. The excitation voltage is varied in small steps through contactors controlled by a frequency relay, so that the secondary frequency of the converter can be maintained exactly at 50 c/s in spite of severe fluctuation on the 60-c/s primary side.

unique nuclear research establishment, which is the outcome of close cooperation between European nations, the proton synchrotron was officially inaugurated in a ceremony which took place on February 5th 1960, since when it has been constantly in operation. The power required for the magnets, which pulsate strongly and rapidly, is furnished by a motor-generator set, the power input to which is kept constant by a Scherbius set. Since extremely strict conditions had to be fulfilled with regard to the constancy and speed of control, the double induction regulator was for the first time replaced by control generators, which are in turn controlled by thyratrons. By this means a control system of high quality was obtained, which has proved most reliable in service. Indeed it has since been discovered that the constancy of the speed of the motor-generator set has a very favourable influence on the control of the magnets. In fact, Scherbius control sets are an ideal means of controlling the power supply to synchrotrons, compared with slip resistors, which suffer from the disadvantages inherent in their heavy losses, the inadequacy of resistance control and the inconstancy of the ohmic value of liquid resistors, due to changes in the electrolyte.

At the present moment a system interconnection converter is in production for the Bernese Power Co. (BKW). It will be used for the supply of power to the single-phase $16^2/_3$-c/s traction system of the Berne–Lötschberg–Simplon Railway (BLS). The throughput of the converter is 8 MW, the induction machine being coupled to a Scherbius machine. Noteworthy are the very stringent conditions laid down regarding control.

The converter has to run in parallel with a pair of synchronous-synchronous converters and has to fulfil the following conditions:

- When running solo it has to couple the two networks flexibly and transfer power from one system to the other in accordance with a preset load-frequency characteristic.
- When running in parallel with existing synchronous-synchronous converters, the Scherbius converter set has to act like a synchronous machine, yet handle the share of the transferred power proportional to its rating.

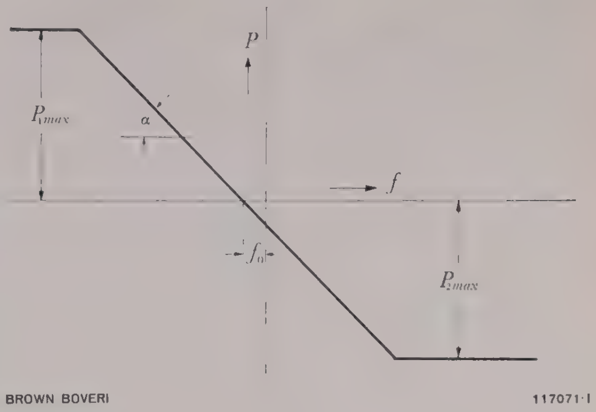

Fig. 103a. – Load-frequency characteristic of the Scherbius converter used for flexible interconnection of power systems

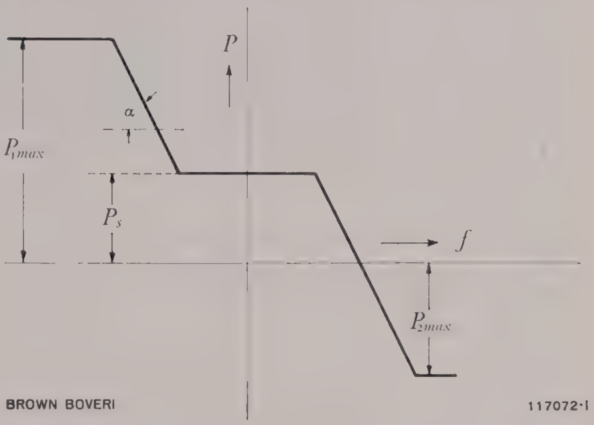

Fig. 103b. – Load-frequency characteristic of the Scherbius converter when running in parallel with synchronous-synchronous converters

P = Output of the converter set
$P_{1\,max}$ = Variable power limit in the forward direction (BKW–BLS)
$P_{2\,max}$ = Variable power limit in the reverse direction (BLS–BKW)
α = Gradient
f = Frequency of the traction network
f_0 = Preset frequency at which the power is zero
P_s = Output in synchronous operation, the value being proportional to the output of the parallel synchronous machines

- The stability of the traction network is endangered if a heavy load is thrown off, in which case the Scherbius machine must be able to assist very rapidly.

Whereas, for the first stipulation alone, the normal Scherbius control system with phase-shifting transformer and induction regulators would have been quite adequate, the second and third conditions

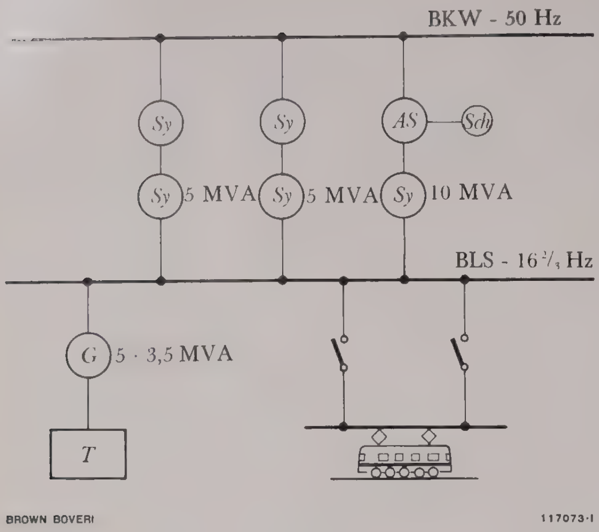

Fig. 104. – Greatly simplified circuit diagram to illustrate the interconnection of the networks of the Bernese Power Co. (BKW) and the Berne-Lötschberg–Simplon Railway (BLS) following installation of a 10-MVA converter with Scherbius control set

Sy = Synchronous machines
As = Induction (asynchronous) machine
Sch = Scherbius control machine
G, *T* = Lumped generators and turbines of the BLS network

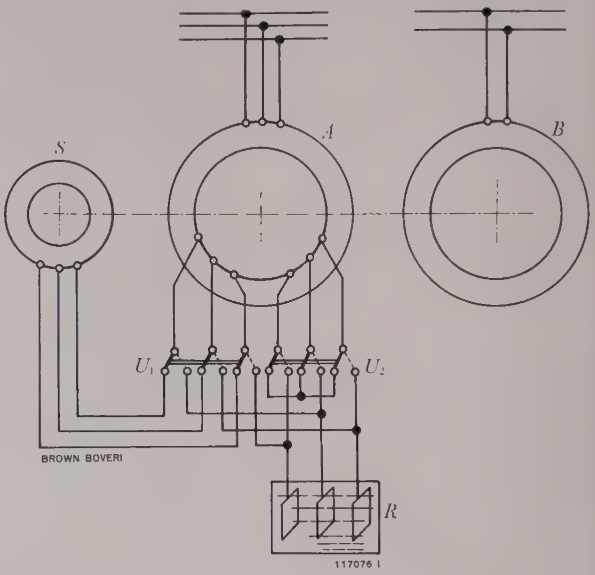

Fig. 105. – Circuit diagram of an interconnection converter, the liquid starter of which is utilized as a slip resistor

A = Three-phase induction machine
B = Single-phase synchronous machine
S = Scherbius machine
R = Liquid resistor
U_1 and U_2 = Changeover switches

With U_1 and U_2 both to the right: induction motor *A* starts through liquid starter with rotor winding in delta.

With U_1 and U_2 to left: Normal running, rotor winding in star and connected to Scherbius machine. With U_1 left, U_2 right: Abnormally high slip, rotor winding connected to Scherbius machine and liquid resistor *R*.

demand the provision of a system of control with a quick response and adaptable to long-distance power transmission systems. An ideal solution to this problem was to adopt the control system developed for the Scherbius set supplied to the CERN, Geneva, with electronic control of the active and reactive power. The additional elements needed for the load-frequency characteristic and stability control are combined in a separate controller. For flexible interconnection of power systems this controller produces a characteristic like that in Fig. 103a. When the frequency is dropping in the traction system, the power drawn from the 50-c/s system must increase. The gradient of the characteristic and its zero, as well as the maximum power in the two directions, can be set on this controller by hand or by remote-controlled potentiometers. When operating with rigid interconnection the controller must have a characteristic like that in Fig. 103b; in this case the power is kept constant within a certain range, regardless of change of frequency. Its magnitude is controlled in proportion to the power of the parallel synchronous-synchronous machines; moreover the value of the output of the synchronous converters is communicated to the controller by a telemetering system.

The stability of the network is endangered if a 100 % load throw-off should occur, for instance when operating at full-load, when all converters and hydroelectric generators are supplying power to the traction system (see Fig. 104). In this case all the machines continue to feed power into the railway network, in accordance with the discharge of the turbines and the rotor angle of the synchronous converters. This energy first of all accelerates the masses of the generators and converters; later these are braked on reversal of the rotor angle of the synchronous machines. This takes place with severe oscillations which, depending on the state of the system, may result in the synchronous machines falling out of step. Being equipped with the electronic control system, the induction machine is able to intervene sufficiently

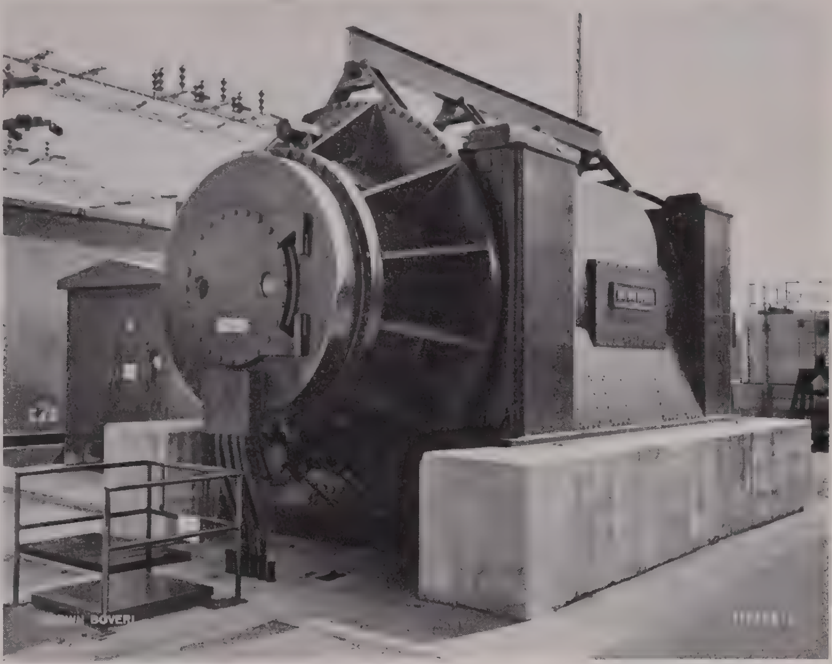

Fig. 106. – Outdoor three-phase synchronous capacitor with hydrogen cooling, installed in the Detweiler substation of the Hydro-Electric Power Commission of Ontario, Canada

Rating	48 MVA over-excited 40 MVA under-excited
Rated voltage	13·8 kV ±5%
Frequency	60 c/s
Speed	900 rev/min

rapidly via the telemetering system, and so transfer energy out of the traction network by changing the direction of its power immediately the load throw-off occurs. The control system itself responds to the power-time integral proportional to the momentary load throw-off.

The possibility of exploiting this method for flexible interconnection of networks is also being contemplated. For normal conditions converters of this kind do not need a particularly rapid control system, because the load and the frequencies vary relatively slowly. But if a fault occurs in the traction network, which the slow-acting regulators of the primary machines can only check with difficulty, the control properties of the converter become quite important. Its supplementary contribution is more effective, the quicker it is changed to overload operation. To enable such sets to remain in operation when the traction system is exhausted, i.e. when the frequency is very low, an arrangement has been devised, by means of which the starting resistor of the induction machine can also be employed as a slip resistor, thus permitting greater slip to be tolerated temporarily. This arrangement exploits the fact that large induction machines are usually equipped with six slip rings in any case. It is therefore not an added complication to provide the rotor winding with three open phases. Under normal conditions one end of each is connected to the Scherbius machine, the other three ends being connected in star. In the event of a fault, the star connection is opened and the liquid resistor cut in, which can take place smoothly if it is set to its lowest ohmic value. For further variation this resistor can be shifted without causing any surges. The relevant circuit diagram is shown in Fig. 105.

F. Synchronous Capacitors

In order to reduce the losses, synchronous capacitors are now being built with hydrogen cooling, which is an ideal system for this kind of machine because the entire body can be sealed gas-tight, requiring no shaft seals. The exciter and slip rings are then housed in a compartment of the casing, which can be sealed off from the rest of the machine when it is not running. Thus for inspecting the exciter or replacement of the brushes it is only necessary to allow the small amount of gas in the exciter compartment to escape. Fig. 106 shows the hydrogen-cooled synchronous capacitor rated 48 MVA, 60 c/s at 900 rev/min, installed in the Detweiler substation of the Hydro-Electric Power Commission of Ontario, Canada.

III. ELECTRIC MOTORS AND DRIVES

A. Modern Designs of Electric Motors

1. A.C. Motors

1.1 Motors to IEC recommendations

The past two-year period represents a milestone in the history of the development of induction motors: from the international aspect by the appearance of the IEC Publication 72–1 (third edition) in 1959, containing a single range of standardized main dimensions and a preferential range of outputs; from the Brown Boveri aspect by the introduction of a complete range of totally enclosed fan-cooled (TEFC) squirrel-cage motors conforming to the above recommendations.[1] Standardization of the motor dimensions allows the manufacturers of driven machines to rationalize to a certain extent in their designs, while the standardized output graduation can help users to save considerably, particularly with regard to storage of spare parts, because the range is limited to a definite number of fixed outputs.

The Brown Boveri standardized motors are divided into two categories, namely the small motors with shaft centre heights up to 132 mm (Fig. 107) and ratings up to 7·5 kW (10 hp) at 1500 rev/min, which are only available as TEFC motors for use in any circumstances. The second category (Fig. 108) comprises the larger motors with shaft centre heights of 160 to 315 mm and ratings up to 130 kW (175 hp) at 1500 rev/min; in this range, as well as for still larger motors, drip-proof enclosure will still be available as an alternative to TEFC. Both categories of motors have been in service for several months in many different situations (Fig. 109 and 110) and, on the whole, were well received by customers. This may be attributed to the properties common to the two categories of standardized industrial motors: reliability, good performance, pleasing appearance.

1.2 New range of splash-proof three-phase induction motors for medium outputs

As power units in industrial plants of all kinds, increasing use is being made of three-phase induction motors, even in the medium-output range. Their simple design, reliability combined with easy maintenance, and their great adaptability with respect to speed, starting torque, starting current and overload capacity on all kinds of process machines, make them a preferred choice.

Based on many years' experience, a completely new range of splash-proof three-phase induction

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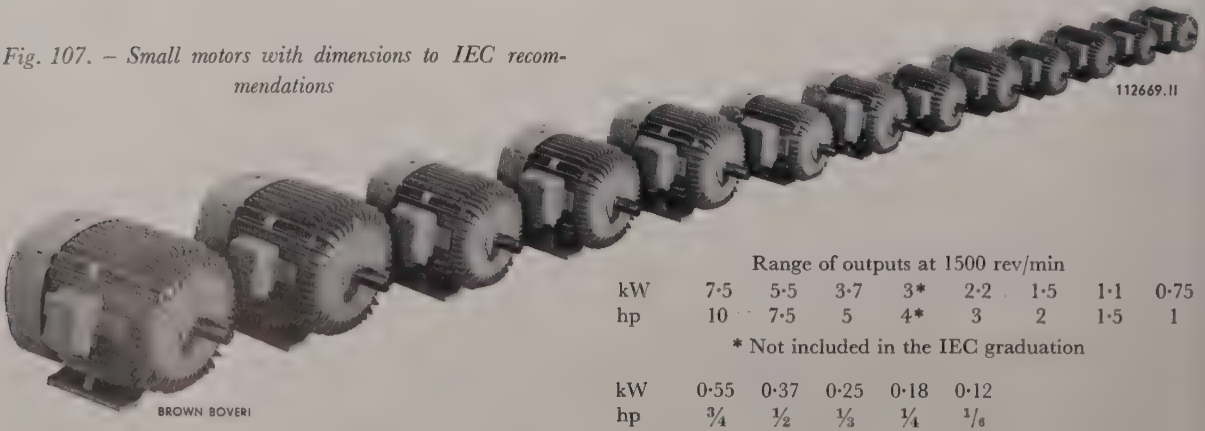
[1] See Brown Boveri Rev. 1960, Vol. 47, No. 3, p. 119–23.

Fig. 107. – Small motors with dimensions to IEC recommendations



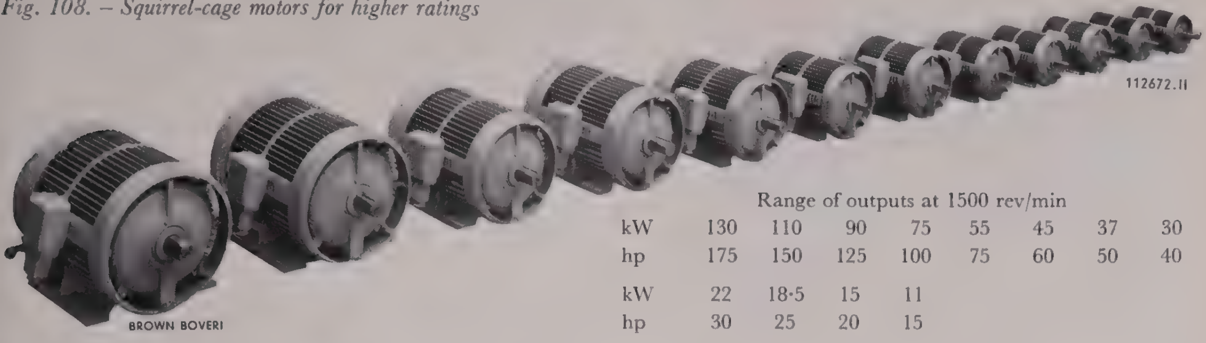
Range of outputs at 1500 rev/min

kW	7·5	5·5	3·7	3*	2·2	1·5	1·1	0·75
hp	10	7·5	5	4*	3	2	1·5	1

* Not included in the IEC graduation

kW	0·55	0·37	0·25	0·18	0·12
hp	¾	½	⅓	¼	⅙

Fig. 108. – Squirrel-cage motors for higher ratings



Range of outputs at 1500 rev/min

kW	130	110	90	75	55	45	37	30
hp	175	150	125	100	75	60	50	40
kW	22	18·5	15	11				
hp	30	25	20	15				

motors has been developed, the principal feature of which is the simple design. New insulating materials, new winding arrangements and effective improvements to the ventilation, have resulted in appreciable increases in outputs. The enclosure of these motors conforms to the specifications for drip and splash-proof (P 21 or 22 to DIN 40050). The output range is from 135 to 820 kW for the four-pole version at 50-c/s voltages of 220, 380 and 500 V.

The stator windings have class E insulation, while the rotor windings of slip-ring motors have class B. The range has three sizes, characterized by the external dimensions of the stator laminations. Each size is available as listed model with four, six, eight, ten or twelve poles, as squirrel-cage or slip-ring motor, and with three different iron lengths.

This new range of motors thus continues where the motors to IEC recommendations (see 1.1) leave

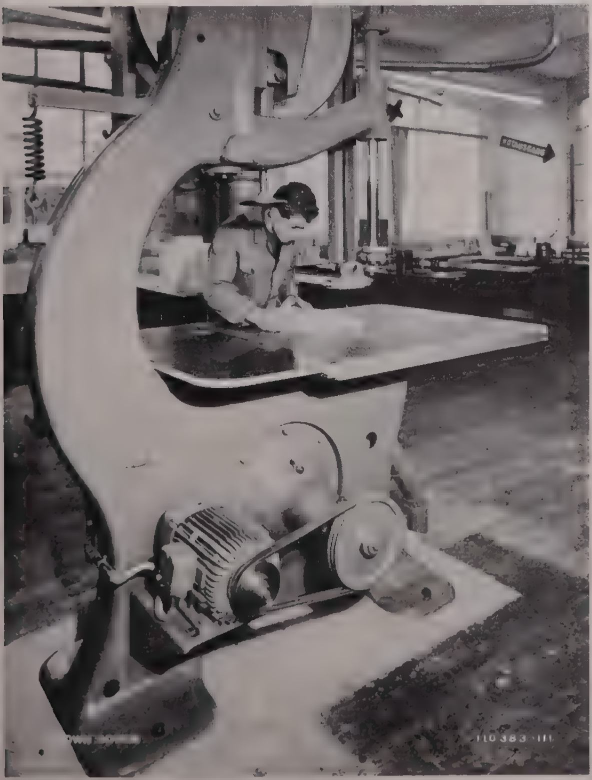


Fig. 109. – Small motor driving a band-saw

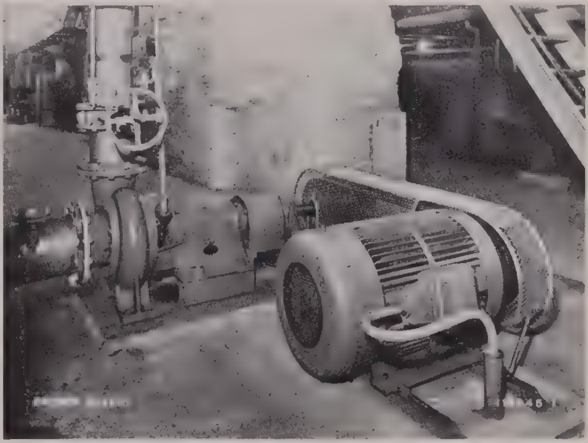


Fig. 110. – Squirrel-cage motor driving a pump

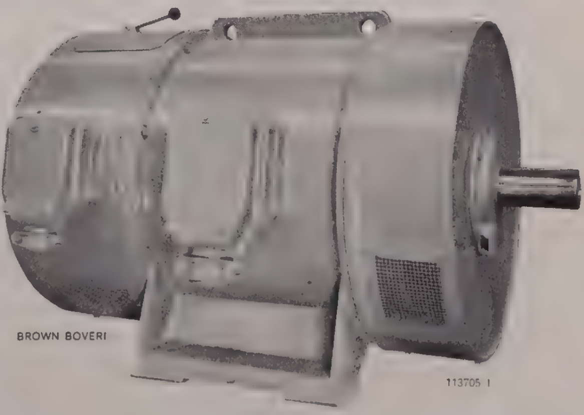


Fig. 111. – Splash-proof slip-ring motor of welded construction, for medium outputs

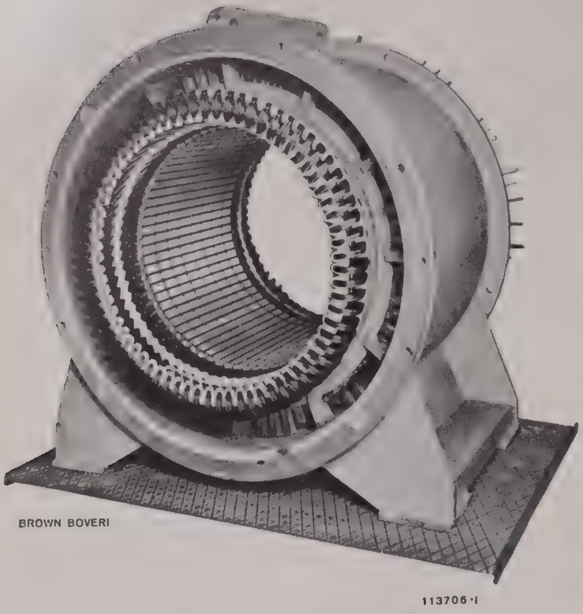


Fig. 112. – Stator of an induction motor of the new range with the winding in position

off. For high voltages of 3, 5 and 6 kV a similar complete range of motors for ratings between 175 and 2800 kW for the four-pole version is being prepared.

The new motors employ welded frames. The basic principle of combining functional aptitude with maximum simplicity governed the design of all components and led to a robust, adaptable range of motors of pleasing appearance.

The number of different components in a single motor size was minimized by combining the iron lengths and the projection of the end-coils, which greatly assists speedy delivery and flexible stocking of parts and spares for a large number of types. In addition to the model illustrated in Fig. 111, other forms are available with unchanged active parts and, to a large extent, the same mechanical components.

An appreciable increase in the outputs was achieved by the use of mush windings in the stator, utilizing varnished flat-wire conductors. They yield

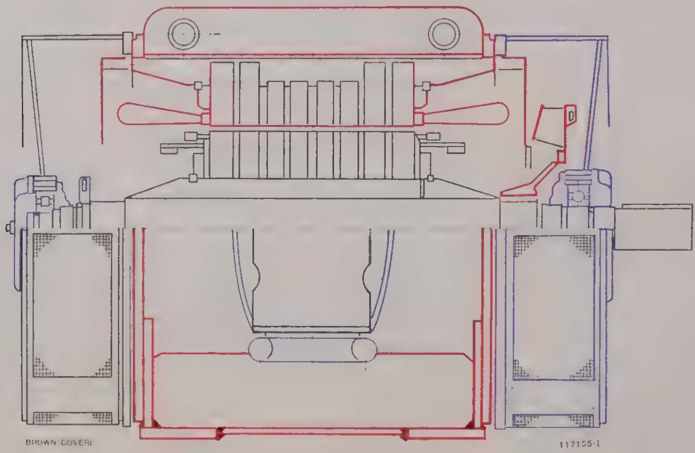


Fig. 113. – Sectional elevation of a squirrel-cage motor of the new range

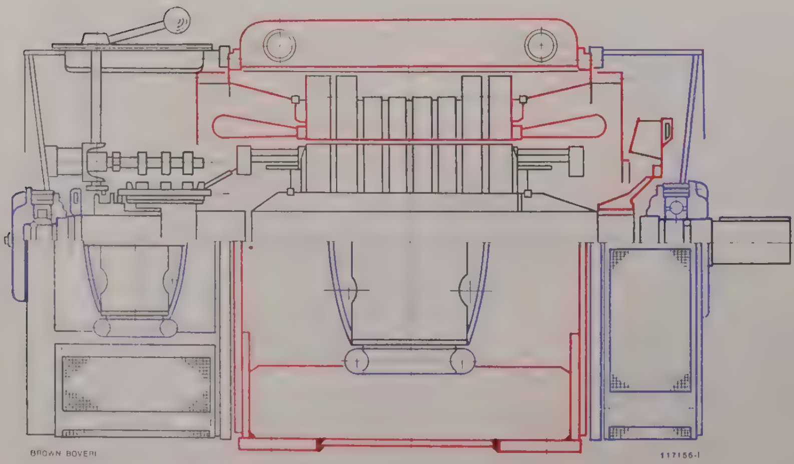


Fig. 114. – Sectional elevation of a new slip-ring motor showing the shorting and brush-raising gear

very good space utilization factors and heat transfer coefficients along the slots, as well as end-coils which are easy to ventilate, the geometrically predetermined shape of which facilitates their insertion in semi-closed slots, also spacing and supporting (Fig. 112). The coil connections are brazed and the windings, after insertion, are strengthened mechanically by treatment with a special varnish, thereby improving their heat transfer. Squirrel-cage rotors are designed normally with double-cage windings.

A sectional elevation of a squirrel-cage motor of the new series is shown in Fig. 113, while Fig. 114 illustrates the slip-ring motor of the same size. The parts marked in red, i.e. the stators and fans are identical for motors having the same numbers of poles, while the blue parts, i.e. the end-shield at the driving end, the bearing assemblies at both ends and the stator terminal boxes, are identical for all types of one size. The broader end-shield at the non-driving end of the slip-ring motor is alike in design for motors with permanent-contact brushes or with brush-raising gear. Roller and plain bearings can be fitted in the same end-shields. Roller bearings can be lubricated in service through grease nipples and are equipped with a grease valve for the expulsion of excess and used grease. The plain bearings are built in one piece and ring-lubricated; they can also be supplied for oil-bath lubrication.

The bearings and shaft extensions of these motors have been adapted to the increased outputs, but can be specially reinforced to withstand the greater stresses imposed by belt drives.

Medium-output motors require a considerable amount of air for cooling, in which respect they often have to conform to special requirements regarding the air inlet and outlet openings. Normally these are directed downwards, as shown in Fig. 111; the design of the end-shields, bearing assemblies, brush-raising gear and rotor terminals permits these openings to be displaced at intervals of 90°, i.e. upwards, downwards, or to either side. These facilities are indicated in Fig. 115. By turning the symmetrical stator through 180° during erection, the position of the stator terminals can also be changed.

Special attention was devoted to the elimination of disturbing noise, in order to comply with contemporary requirements regarding the installation in factories. For the subjective sensitivity to sound it is just as important for the frequency of the noise to be as low as possible, as it is for the total volume produced by the addition of the magnetic hum and the noise created by the fan and bearings. When the fans are well designed aerodynamically, the noise produced increases as a high power of the peripheral speed, which itself determines the necessary pressure produced by the fan and cannot therefore be reduced indiscriminately. Following exhaustive investigations, fans were devised for this range of motors, producing only a moderate noise at frequencies below 300 c/s. The magnetic hum of three-phase machines is mainly caused by harmonic fields in the air-gap. Their occurrence and strength are primarily determined by the ratio between the number of slots in the stator and rotor which, in the new range of motors, was made such that very little magnetic hum may be expected. Ordinary commercial types of roller bearings are employed; if the small amount of noise they make is to be eliminated altogether, it is preferable to employ plain bearings.

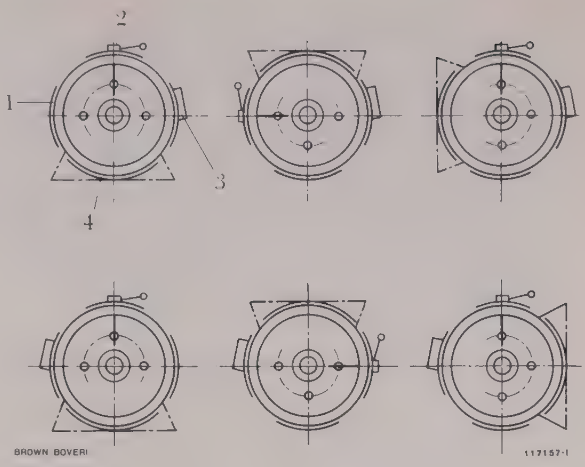


Fig. 115. – Alternative positions of the ventilation openings, rotor terminals, mechanism for the shorting gear, obtained by mounting the end-shields and bearing assemblies differently

1.3 Large boiler feedwater pump motors

Among the numerous motors which have been supplied in recent years for driving the feedwater pumps of boilers, there are some interesting new designs. In most cases these are two-pole squirrel-cage motors for high voltage, coupled either rigidly or flexibly with the pump, if the discharge of feed water

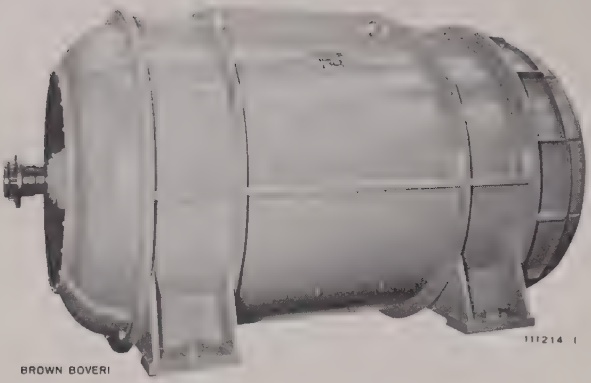


Fig. 116. – Totally enclosed fan-cooled motor of a feedwater pump

1800 hp, 2300 V, 3000 rev/min, 50 c/s, suitable for subsequent conversion to 3600 rev/min, 60 c/s.

has to be controlled by throttling. For more stringent conditions intermediate hydraulic transmissions are used, or even slip-ring motors with speed control by resistors in the rotor circuit, or for very high outputs controlled without loss by means of a Scherbius cascade.[2]

Owing to the amount of coal-dust in the atmosphere of most boiler-houses, as well as its high temperature, the air cannot be employed for cooling the motors direct. Up to ambient temperatures of 40–50 °C totally enclosed motors may be used, in which only the clean air inside the motor serves as a direct coolant, while the external air provides indirect cooling. On account of the double heat transfer, however, the utilization factor of the active parts of this design is lower than for directly ventilated machines, in spite of the increased surface area of the enclosing wall which acts as the heat exchanger. Since, with the larger sizes of motors, the losses increase more rapidly than the surface area, an upper limit is imposed on the outputs of motors of this kind; for the four-pole model it is around 3000 kW. The main advantage of the totally enclosed fan-cooled design (Fig. 116) is that it is independent of any supply of coolant. The noise of the external fan is appreciably damped by connection to ducts, and can also be reduced by fitting specially shaped cowlings at the air inlet and outlet. At the same time the unwelcome blast effect of the air outlet at the driving end is avoided.

Pipe-ventilated motors (Fig. 117), and those equipped with water coolers (Fig. 118) permit full advantage to be taken of the active parts at high speeds, because the fan pressure needed to overcome the resistance of ducts of good aerodynamic design and reasonable length, and of water coolers, can be adequately dimensioned. There is no restriction on the outputs of this kind of motor which, compared with the totally enclosed motor, possesses the additional advantages of complete freedom from draughts at the point of installation combined with reduced noise. Air intake through ducting is dependent upon a suitable supply point being available not too far away; in special circumstances the air intake may be filtered, but this demands constant attention. If there is a cheap supply of water available at temperatures not exceeding 30–35 °C, the model with closed air circuit and water-cooled heat exchanger is preferable because contamination of the machine by the coolant is completely avoided, as with the totally enclosed design. The heat exchanger may be mounted above or at the sides of the motor, where it does not occupy any additional floor space (Fig. 118).

Continuous operation demands high efficiencies; outlay to reduce losses is recovered by the reduction in the cost of power. For the high-speed motors, whose fan and windage losses represent quite a large proportion of the overall losses, it is essential to exercise a certain amount of restraint in the specific utilization

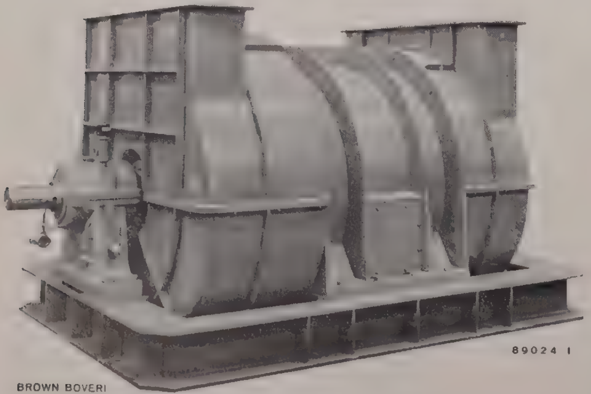


Fig. 117. – Pipe-ventilated feedwater pump motor

for connection to inlet and outlet ducts. Rating 1850 hp, 3000 V, 3000 rev/min, 50 c/s.

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[2] P. RAUHUT: Lossless control of pump drives by Scherbius sets. Brown Boveri Rev. 1960, Vol. 47, No. 12, p. 845–59.

of the active material so that, while reducing the iron losses and heat generated by the passage of current, the air throughput needed to dissipate these losses is also diminished. For high outputs it may be preferable to replace the centrifugal fans by axial fans, which produce the pressure needed for the reduced throughput at a higher efficiency. The windage losses of the rotor can be reduced by enclosing the end-coils and shorting rings (Fig. 119).

The stator windings are mostly compounded coil windings laid in two layers in open slots. The appreciable forces to which the end-coils are subjected when the motor is switched on, particularly in squirrel-cage motors, are absorbed by a new system of mechanical bracing.

The rotor design is mainly based on stably overcoming the high centrifugal forces and thermal expansion, to ensure a permanent good balance, regardless of the operating conditions.

1.4 Glandless heavy-water pumps

For the "Diorit" reactor at the Swiss Nuclear Research Station at Würenlingen two vertical motor-driven pumps were supplied for pumping the heavy water. These are interesting on account of their constructional and technological features. The discharge of each pump is 65 litres/s at a static head of 38 m and a density of 1·12 kg/dm^3. The maximum temperature attained by the heavy water is 60 °C. The three-phase induction motor is designed for an output of 40 kW at 220/380 V and a speed of 2900 rev/min.

The pump and its motor form an integral unit, which is inserted into the D_2O circuit by direct flanging on to the piping through the pump casing. Apart from these joints, sealed doubly with special rubber gaskets, the motor-driven pumps are hermetically sealed, the rotor running in the liquid pumped and the bearings being lubricated with D_2O. The impeller is mounted overhung at the top end of the motor shaft and, like the spiral casing, is of stainless steel. This unconventional suspended design with the pump at the top end was rendered necessary by the fact that the piping had to be run along the ceiling. Fig. 120 shows a sectional elevation through the pump.

Owing to the stipulation that all parts coming into contact with the D_2O must be absolutely free from corrosion, it was necessary to "can" the rotor laminations complete with winding and to line the stator bore with sleeves of stainless non-magnetic steel. In the air-gap these sleeves had to be very thin indeed in order to keep the increase in magnetic resistance and the resultant eddy-current losses within tolerable limits. The shaft, the end-plates of the rotor and stator, as well as all metallic parts of the bearings, are of stainless steel. Some of the special welding problems which had to be solved were dealt with in an earlier publication.[3]

The dissipation of the heat generated inside the motor is intensified by automatic renewal of its small heavy-water content. Through an external pipe connected to the pressure side of the pump, heavy water

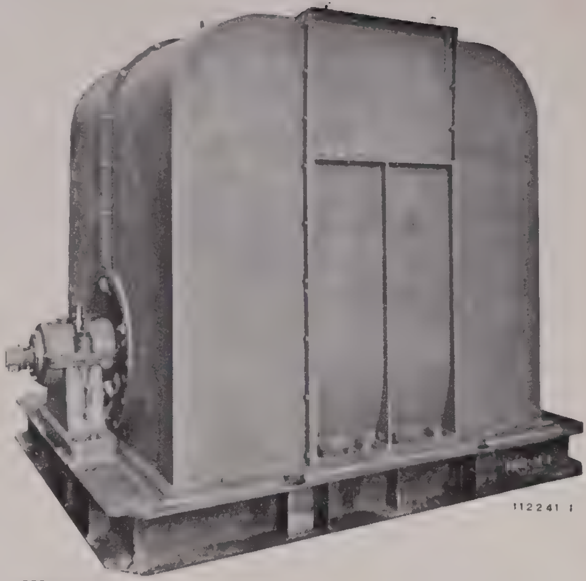

Fig. 118. – Totally enclosed feedwater pump motor with built-on water cooler

4200 hp, 6300 V, 3000 rev/min, 50 c/s.

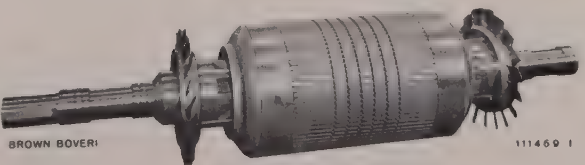

Fig. 119. – Rotor of a squirrel-cage feedwater pump motor

4200 hp, 6 kV, 3000 rev/min, 50 c/s, with axial fans and enclosed coil-ends.

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[3] A. LÜTHY: Special welding problems in nuclear engineering. Brown Boveri Rev. 1958, Vol. 45, No. 6, p. 272–9.

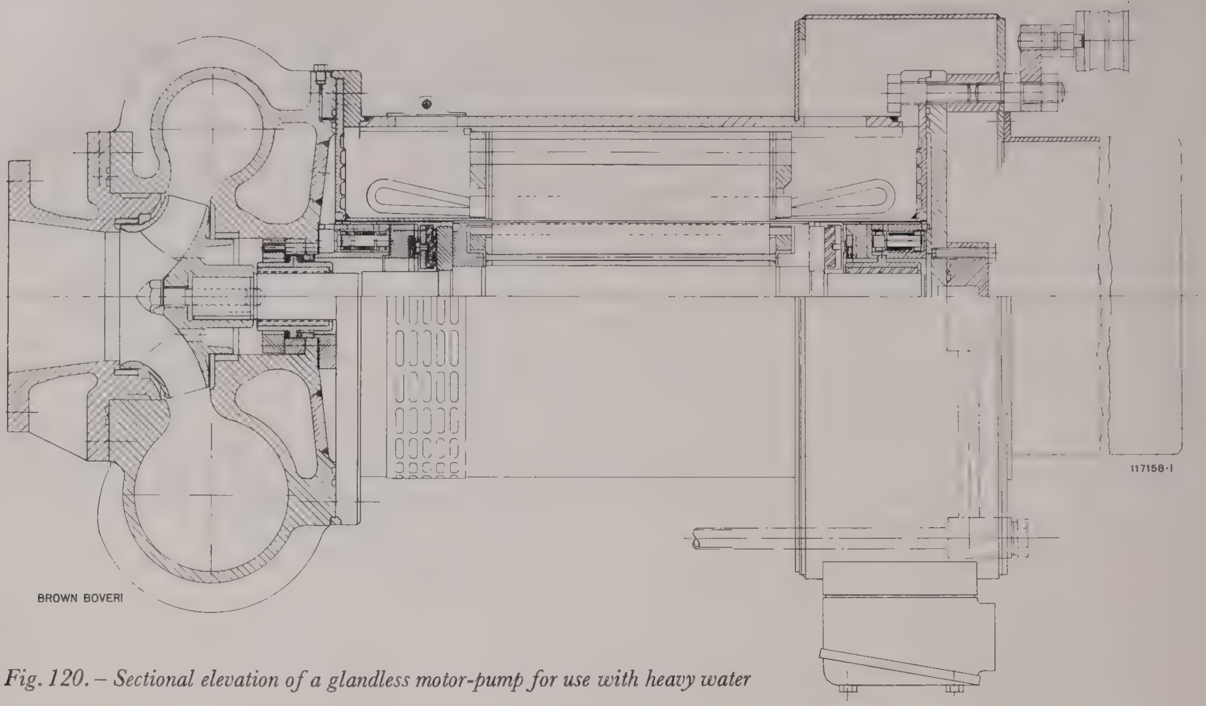

Fig. 120. – Sectional elevation of a glandless motor-pump for use with heavy water

from the discharge circuit is pumped into the motor. It flows through the bearings and the air-gap, returning to the discharge circuit through low-pressure communication openings. By providing this cooling circuit parallel to the discharge circuit, the complication of an autonomous internal closed circuit is avoided; however, it can only be employed in this case owing to the relatively low temperature of the heavy water. The water entering at the bottom exerts an upward thrust on the rotor which, added to the upward pressure produced by the pump, creates a resultant upward force, which more than overcomes the weight of the rotor when running at rated conditions. To withstand the alternating forces of limited magnitude there are two thrust bearings, lightly sprung towards each other.

The low viscosity of the D_2O must be accompanied by a corresponding reduction in the specific load on the thrust bearings and very small play in the guide bearings. The fact that the lubricating film is only about 1/10 to 1/20 as thick as the oil film in a bearing carrying equal load, imposes much greater demands on the accuracy of machining and the superficial quality of the running parts of stainless steel and the supporting parts of graphite.

The heavy water in the discharge circuit must be extremely pure. The pumps had to be submitted to special cleaning processes before assembly, which was also carried out in a dustless area.

1.5 *Motors for pumped storage plants*

The general trend as regards motors for pumped storage plants and transfer pumps is towards higher speeds. Already turbo-type motors for 3000 rev/min are being offered.

At the Stafel pumping station of the Grande Dixence scheme in Switzerland three synchronous motors rated 9·6 MVA at a power factor of 0·95 and 1500 rev/min have been taken into service. These motors are designed for direct-on-line asynchronous start at full line voltage. When the pump is uncoupled the motor can be employed as a phase advancer. During the winter months they are run in the reverse sense as generators, the blades of the fans being designed so that they can be turned round after removal of the cover-plate.

The Linth-Limmern Power Co. ordered two pump motors rated 20·3 MVA at a power factor of 0·95 and 1000 rev/min for their Tierfehd generating station in Switzerland.

1.6 *Scherbius sets and phase advancers*

Machines of this kind are built for use in conjunction with various kinds of drives.[4] Here the intention is only to deal with a field for which the Scherbius machine is ideally suited, namely pumps, fans, blowers and compressors.[5] Control of the discharge of these machines (liquid, gas or air) is often stipulated. Direct intervention by throttling involves serious loss of power; variable-pitch blades are efficient, but are complicated and expensive. The problem can, however, be solved in an ideal manner from the drive side by varying the speed, for which the Scherbius machine is well suited. It renders a normal three-phase motor capable of speed variation without losses and may be employed with advantage in situations where a wide speed range is not generally required. The remarks which follow describe some new installations of this nature.

The city of Hanover drew up a modern and liberal plan for a new waterworks in Fuhrberg to supply the city with drinking water. The discharge capacity along the 24 km pipeline had to be adapted to the requirements. Two main pump units were chosen, one of which is continuously running, the other acting as standby. Owing to the good results which had been obtained with a Scherbius set in another of their pumping stations, two of these machines were ordered for the new installation, where each can be connected to either of the main pump motors. The pump speed can thereby be varied between 1180 and 1680 rev/min, corresponding to a discharge of 1015–1810 m^3/h. During acceptance the following figures were measured: Speed 1680 rev/min, power at the shaft 916 kW, overall efficiency 94·25%. Throughout the whole speed range the power factor is constant in the region of unity. A view of the pump-room can be seen in the coloured plate X.

An interesting system employed for the first time consists of a Scherbius set common to two cooling-water pumps in a power station. In this case the accessories of the Scherbius set were reduced to a minimum. The motors are shunt excited from a setting transformer, assisted by a fixed resistor and a small transformer for varying the phase angle. The speed of the main motor is varied almost steplessly by the setting transformer. The Scherbius machine may be used to control one motor alone, or both together. This installation has been in service since May 1955 (Fig. 121).

About the same time a drive for a blast-furnace blower was taken into service. It is designed for 3650 kW at full speed and for reduction to 78·5% of the maximum speed. The synchronous point was conveniently arranged to be in the middle of the range of variation, thereby keeping the type rating of the Scherbius machine small, while attaining a good efficiency across the whole range. Illustrations of this installation can be seen in Fig. 122 and 123.

In another steelworks it was decided that, for the drive of a compressor, it would be possible to dispense with the motor driving the Scherbius machine by coupling the latter to the main drive direct. In this case the output is 4300 kW, with a speed range amounting to 10·4% of the maximum.

Further drives for compressors, fans and pumps are at present under construction. An interesting installation is one in which the motors driving four pumps of different capacities can be connected to a single Scherbius machine, as required. Here the newly developed arrangement for stepless speed control with a setting transformer was also adopted.

The *statorless phase advancer* is the simplest kind of commutator machine.[6] It is used for improving the power factor of drive motors having a heavy continuous load, and has therefore proved popular for use with wood-grinders and cement mills. By means of the phase advancer it is even possible to increase the output of the motor in many cases; at least the pull-out torque can be increased. These machines are now being built in the new vertical form without sole-plate. Only a small space is occupied; the rotor runs in roller bearings, thus reducing the friction losses. The type ratings have also been considerably improved.

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[4] P. RAUHUT: Scherbius machines for speed control, power factor correction and power regulation of induction machines. Brown Boveri Rev. 1951, Vol. 38, No. 5/6, p. 132–47.

[5] P. RAUHUT: Lossless control of pump drives by Scherbius sets. Brown Boveri Rev. 1960, Vol. 47, No. 12, p. 845–59.

P. RAUHUT: Scherbius control sets for blower and compressor drives. Brown Boveri Rev. 1960, Vol. 47, No. 12, p. 860–7.

[6] H. KOCH: The statorless phase advancer in its present form. Brown Boveri Rev. 1961, Vol. 47, No. 12, p. 868–74.

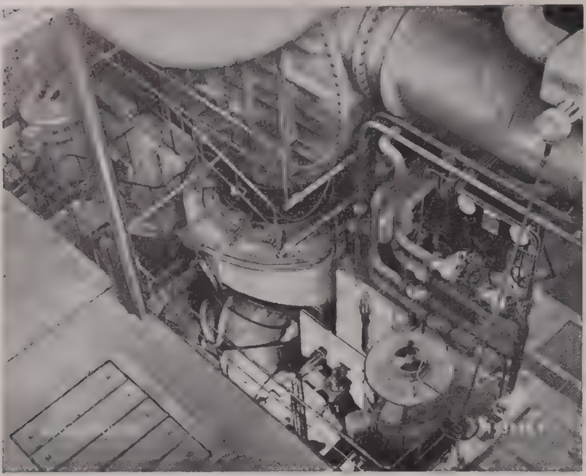


Fig. 121. – Condenser with two cooling-water pumps

Left and right in the pit are the motors driving the cooling-water pumps. The speed of the two pumps can be smoothly controlled, separately or jointly, by means of a Scherbius machine.

1.7 Shunt commutator motors

For drives requiring variable-speed motors, the choice is between the three-phase shunt commutator motor and the d.c. motor either with Ward-Leonard control or fed by a rectifier. The d.c. motor is ideal for use with electronic controllers with which very rapid and accurate speed control is obtained. But if the stipulations regarding the control system are not unduly severe, or if it is not serious for the set speed to vary slightly with load, the rotor-fed shunt commutator motor renders excellent service. Its undisputed advantage lies in its ability to be connected direct to the three-phase mains and in containing its own control elements—the brush gear. It therefore does not require any extra space for the supply and control gear. With it the speed can be varied continuously, almost without loss and at optimum power factor. These advantages have lately gained added significance in that the motor output for a given volume has been considerably increased. An example is a motor rated 480/216 hp at 1200/540 rev/min, used to drive a generator in one of the test laboratories in the factory (Fig. 124).

One of the important spheres in which the commutator motor continues to occupy a leading position is in the cement industry at home and abroad. Large outputs are required for driving rotary kilns and the primary and exhaust fans. Interesting drives of this kind have been supplied to works in USA and Australia. The fact that this Company was asked to supply all the commutator motors for the works of the Dundee Cement Co., Michigan, deserves particular mention, as this plant has been referred to as "the most modern and efficient in the world" (see Fig. 125 and 126).

Drives of fans and compressors form one of the main fields of application for commutator motors.

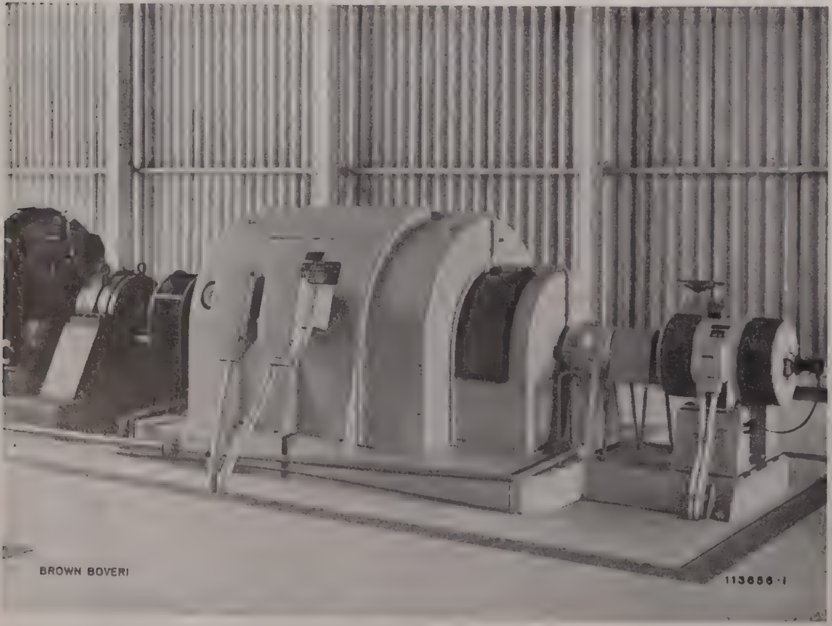


Fig. 122. – Drive of a blast-furnace blower

Rated 3650 kW at top speed, variation possible down to 78·5 %. From left to right: blower, gear, motor, frequency converter. The latter permits running at super-synchronous speed.

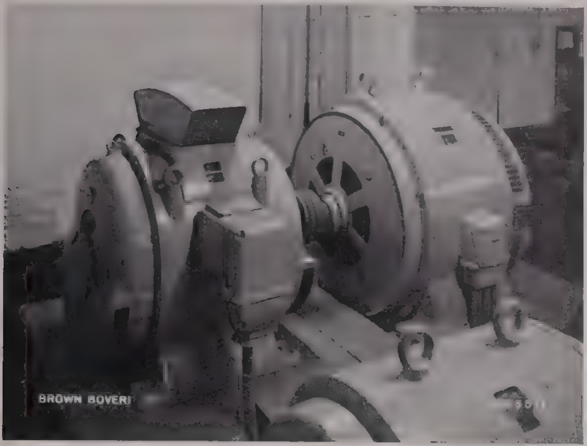


Fig. 123. – The Scherbius set belonging to the motor in Fig. 122

Right: the Scherbius machine; left: its drive motor. In this case the Scherbius set is installed in a separate room.

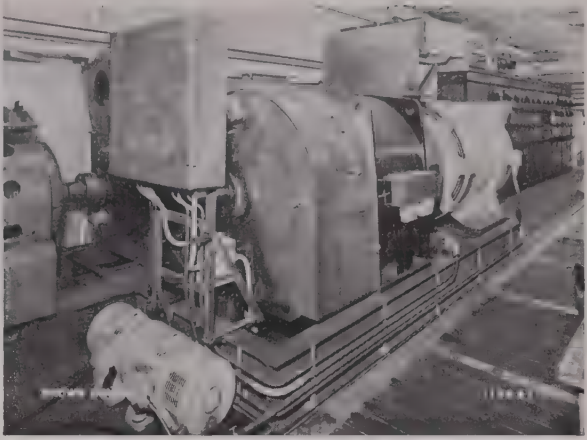


Fig. 124. – Converter in a test laboratory

Left: shunt commutator rated 480/216 hp, for 1200/540 rev/min; right: synchronous generator for variable frequency.

Examples are the drives of primary and secondary-air fans in boiler-houses, with automatic speed control by pneumatic servo-mechanisms on the brush rockers; Fig. 127 shows drives of this kind in the boiler-house of the Baden works; Fig. 128 shows the fan drive in an air-conditioning plant.

For driving rotary printing presses, where commutator motors are widely used, a new model has been brought out with an easily detachable two-piece air filter at the driving end, and with a fan in front of the bearing at the commutator end (see Fig. 129). The fan extracts the warm air and expels the carbon dust from the brushes by the shortest route into the atmosphere.

The avoidance of additional supply and control elements has proved especially advantageous for the employment of shunt commutator motors to drive large presses in production lines in the automobile industry. These presses are equipped with flywheels, which have to perform some of the work of pressing, losing some of their speed in the process. The output of the motors is dimensioned so that the flywheel can be accelerated up to its set speed within a definite period after completion of the pressing operation. The brush-gear of the motors is equipped with a remote-controlled servo-motor. To ensure that the flow of work through the presses is uniform down the whole line, the motor speeds of successive presses are co-ordinated by means of these servo-motors.

It is many years now since Brown Boveri first employed a commutator motor for driving a funicular railway; the same type of motor has also given excellent service with chair-lifts and ski-hoists. An interesting feature is a supplementary device, which can be added without involving unduly heavy costs, enabling the motor to be run at very low speed for the inspection of the rope. This was employed for the first time on the Clavadeleralp ski-hoist near Davos (Fig. 130).

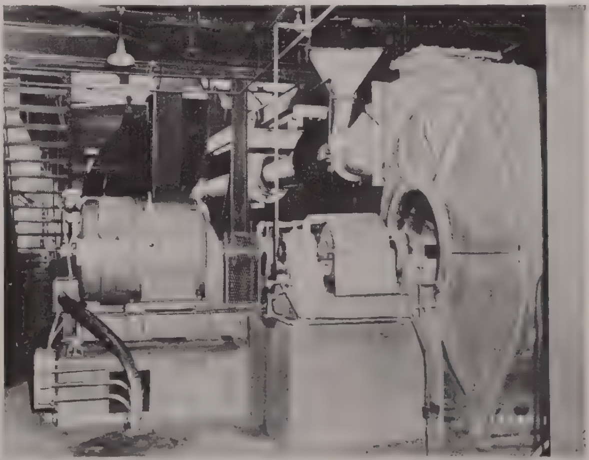


Fig. 125. – Primary-air fan of a rotary cement kiln, driven by a shunt commutator motor

145 kW at 1050 rev/min, 440 V, 60 c/s, speed range 1:2; transmission by belt drive. The pulley at the motor end is driven through a special gear train mounted with the motor on a common sole-plate.

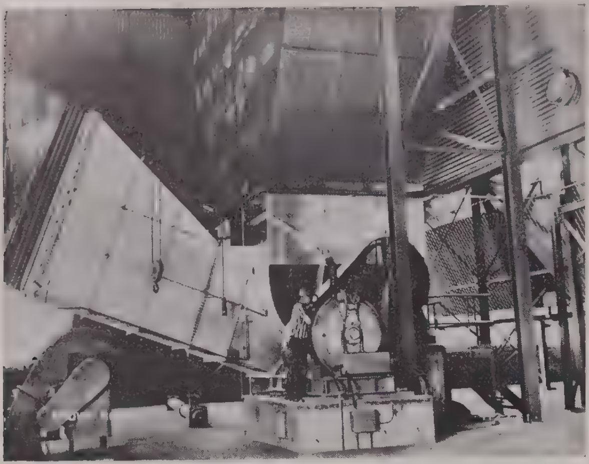


Fig. 126 – Exhaust fan of a rotary cement kiln, driven by a shunt commutator motor

185 kW at 720 rev/min, 440 V, 60 c/s, speed range 1:3; the mechanical arrangement is the same as in Fig. 125.

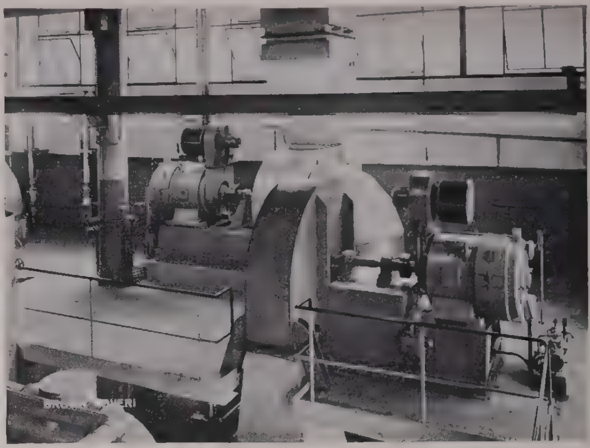


Fig. 127. – Drives for primary and secondary air blowers in the boiler-house of Brown Boveri, Baden

Right: f.d. fan with shunt commutator rated 65/7 hp, 1450/480 rev/min; left: i.d. fan with shunt commutator motor rated 90/5·5 hp, 960/380 rev/min. Each of these motors is cooled by a built-on fan which draws in its air through a filter. The speed and, in consequence, the air intake is controlled automatically. The motors are operated pneumatically (see linkage on the extreme right).

2. D.C. Motors

The tremendous pace at which steelworks and rolling mills have been built and extended in recent years has led to a continued heavy demand for large d.c. machines. An example is the continuous merchant mill of the Tata Iron & Steel Co. Ltd., the largest concern of its kind in India, for which Brown Boveri supplied all the electrical equipment, including 12 d.c. motors with ratings between 400 and 700 kW at a basic speed of 350 rev/min. This installation has now been in service for several months. Another installation of comparable size is at present being erected at the Jamshedpur works of the Indian Steel and Wire Products Ltd.

A new development is a reversing motor for a blooming mill of the Svenska Kullagerfabriken, Hällefors, Sweden, in which self-aligning roller

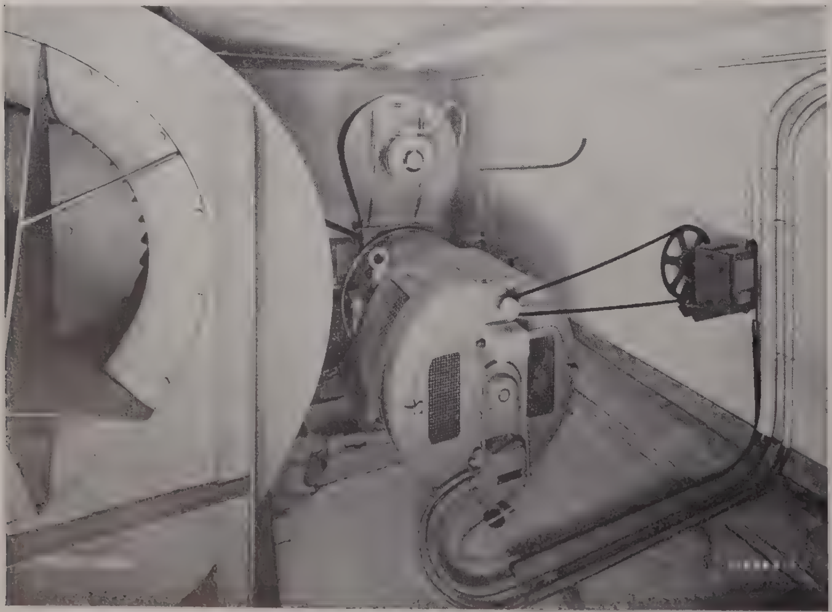
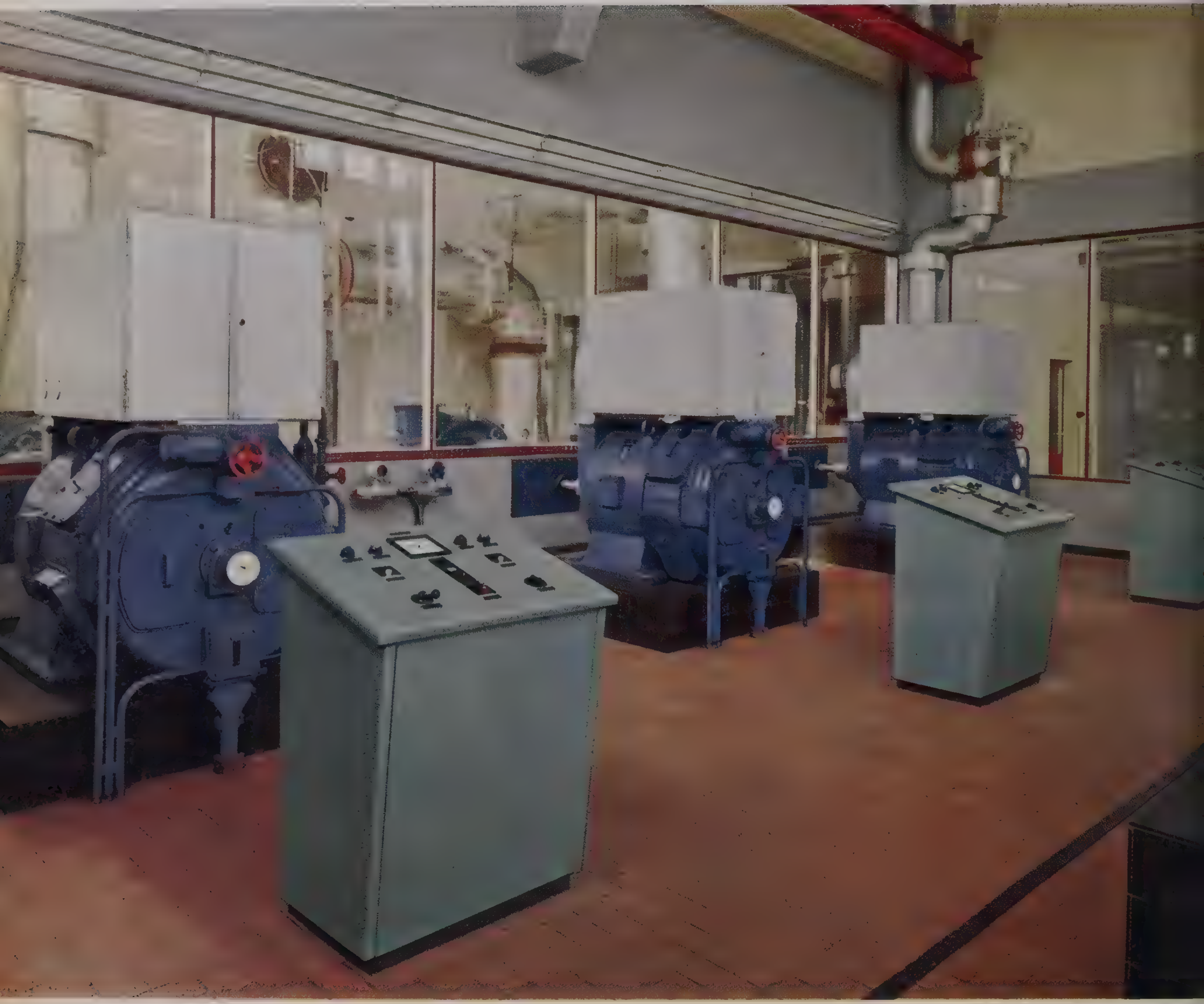


Fig. 128. – Fan drive of the air-conditioning plant in a large Zurich department store

This installation contains several fans driven by shunt commutator motors. On the left in this picture is part of the blower for the supply of fresh air. The commutator motor is rated 55/7 hp at 1300/650 rev/min; it has a built-on fan. The speed is controlled in function of the air pressure. The chain transmission is for control.

VII

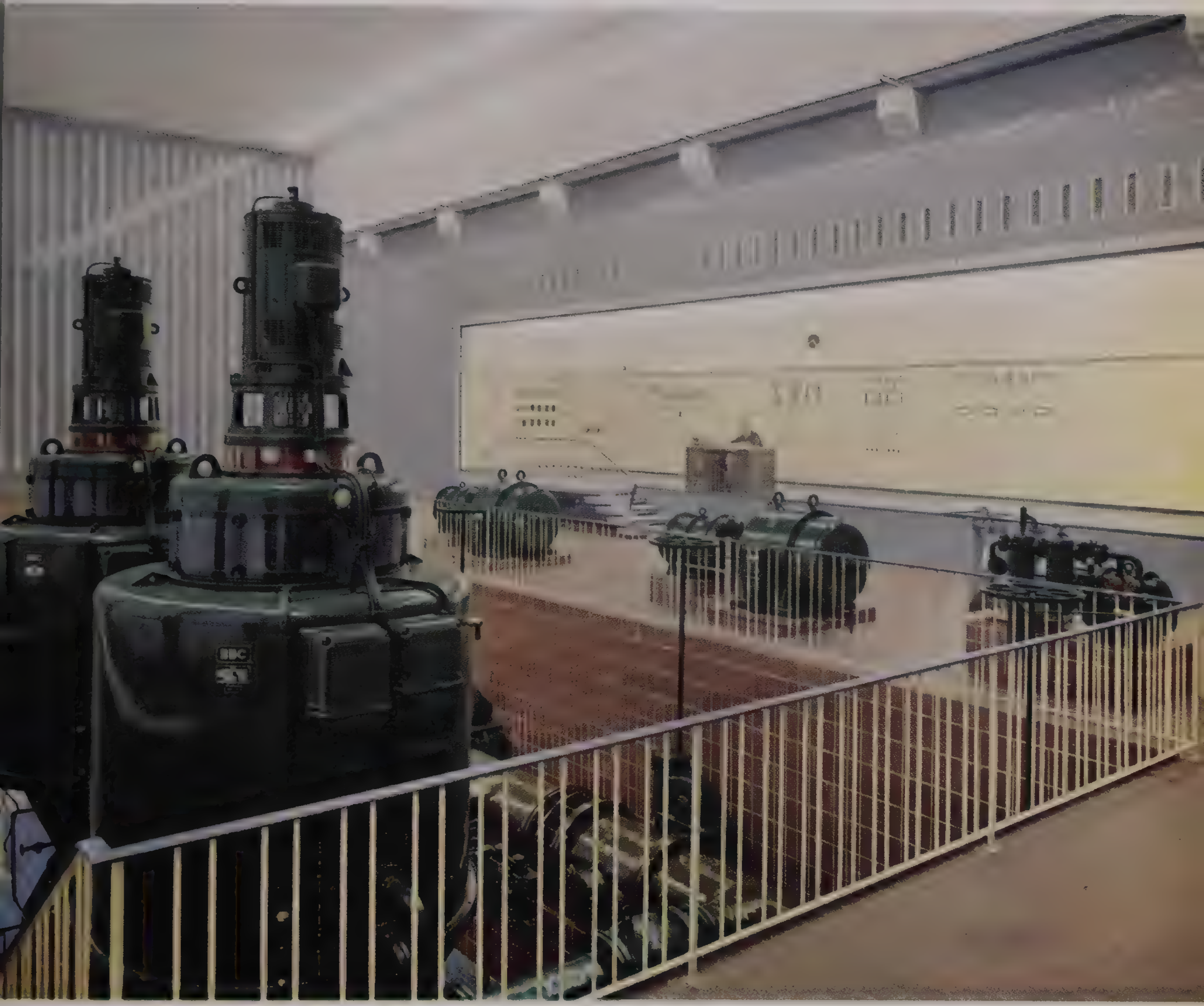
VIII



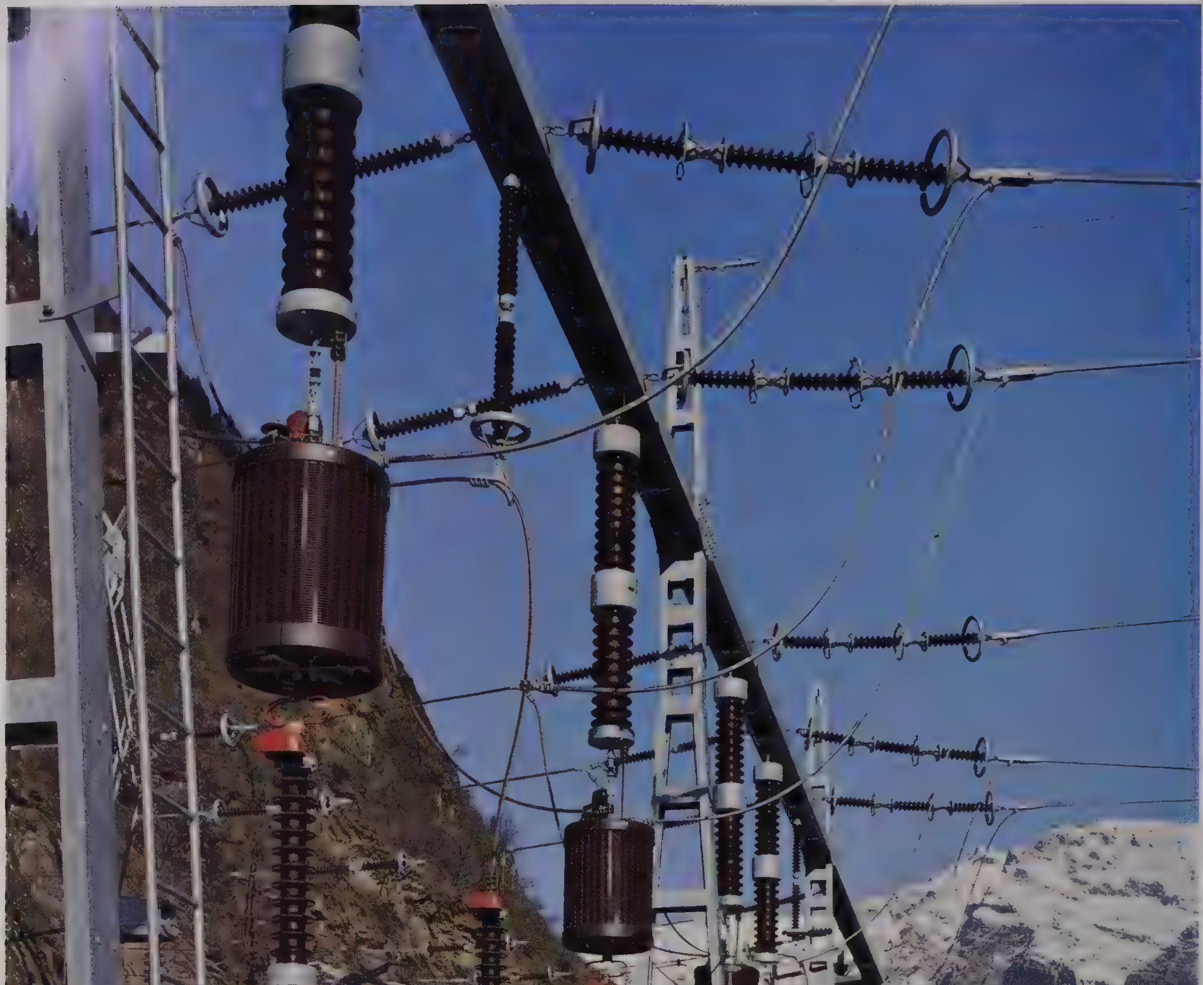
IX *Three-phase shunt commutator motors equipped with closed-circuit coolers, driving gas blowers in the Basle City Gasworks*

◀ VII *220-kV airblast circuit-breakers in the switchyard attached to Sils power station of Kraftwerke Hinterrhein, Switzerland*

◀ VIII *Special transport for a large transformer rated 400/3 MVA, $420/\sqrt{3}$ kV, seen crossing the Rhine bridge at Ragaz on its way to Sils power station. The weight of this single-phase unit is 92 t*



X *Fuhrberg pumping station, supplying drinking water for Hanover, showing two vertical pump sets driven by three-phase induction motors rated 830 kW each at 1470 rev/min. At the rear are the associated Scherbius control sets and, behind the glass panel, the control room*



XI *Soazza substation of the Misoxer Kraftwerke, Switzerland, showing the equipment coupling the carrier sets for telephony and distance protection transfer signals to the 220-kV line to Sils (Grisons) and Mese (Italy)* bearings were employed for the first time instead of the previously conventional ring-lubricated plain bearings. The data of the motor are:

Effective output	2900 kW
Maximum output	9250 kW
Rated voltage	800 V
Rated current	3850 A
Speed	0 ± 60/120 rev/min
Cut-out torque	150 mt

This blooming mill was commissioned early in 1960 and has been running very satisfactorily since (Fig. 131).

Last year two double-armature reversing motors with a rated output of 4500 kW each at 40 rev/min and a maximum output of 12 300 kW were ordered, and have since been completed. One interesting

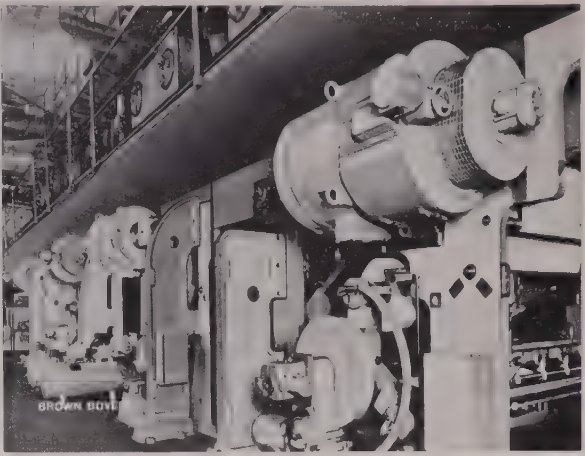


Fig. 129. – Four three-phase shunt commutator motors used to drive a rotary printing press

The design of the motors is ideally suited to that of the driven machine. The filter and fan are combined with the motor.

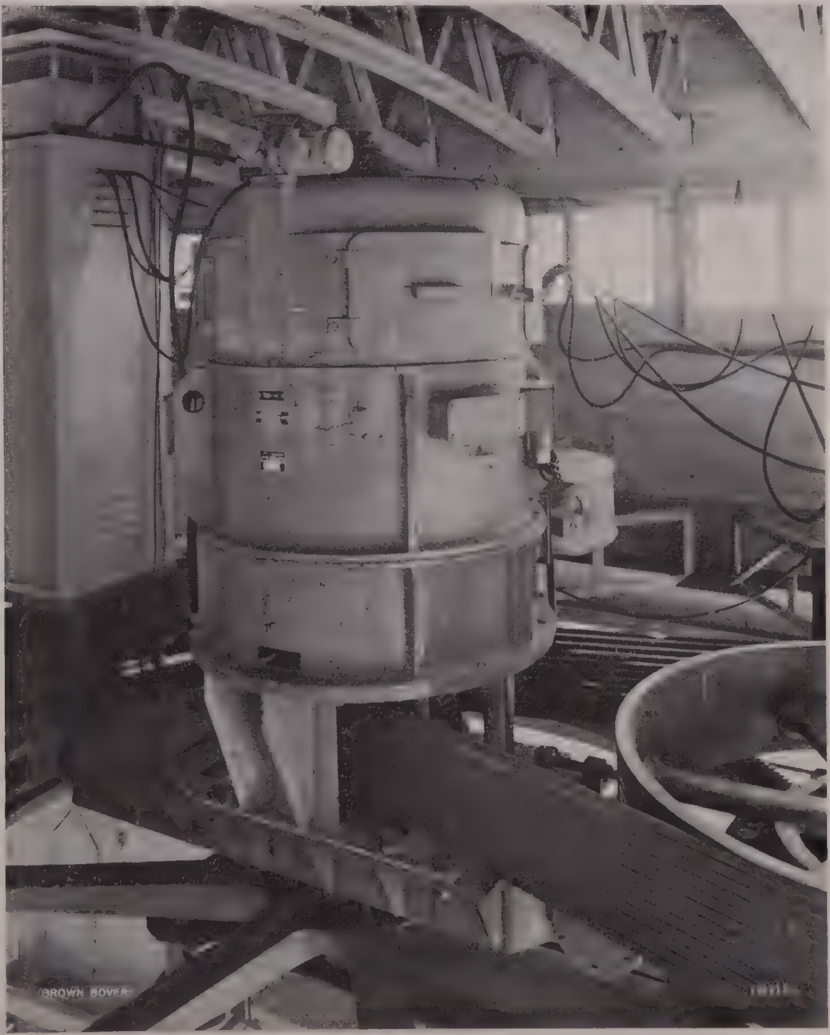


Fig. 130.– Drive of the Clavadeleralp ski-hoist, Davos, Switzerland

Owing to the speed of the commutator motor (170 hp, 1050 rev/min, speed range 3·3:1) being variable, it is easy to adapt the speed of the rope to the snow conditions and the number of skiers waiting. For inspection of the rope, the speed can be reduced to 7% of the normal value.

structional feature is that the motors have only wo bearing pedestals, while the rotor spider is in four parts: the two shaft extensions which are supported by the bearings, and the two sections carrying the rotor body. The commutators are on the outside ends, thus assuring easy access to the brushes and commutators.

B. Control of Industrial Drives

1. Brown Boveri Electronic System for Control and Automation

In the age of automation the electrical equipment of industrial installations imposes a wide variety of demands on the control systems. Brown Boveri have been closely studying the field of automatic control with intense vigour for a number of years. Supplementing the conventional electro-mechanical, pneumatic and hydraulic elements which have been employed for a long time, recent years have witnessed the arrival of numerous elements based on electron tubes, transistors and transductors. These have proved their qualities in a great many large and small installations in all parts of the world.

The Brown Boveri electronic system, a standardized system of "building-block" elements for industrial electronics, grew up from these. It is a flexibly combinable system of mutually matched electronic units, capable of performing the tasks of measurement, open or closed-loop control, memorizing, computing, logical decision and data processing of a general nature. For the execution of this wide variety of tasks, four categories of units were devised, named according to the fields in which they are primarily employed.

- Range 1 (power engineering applications) is employed mainly in conjunction with the control of electrical machines and power equipment.
- Range 2 (counting applications) is used in the construction of numerical control systems.
- Range 3 (tele-operations) for the transmission of remote-control commands, signals or telemetered measurands.
- Range 4 (computer applications) for use where complex logical decisions have to be made at very high speed and arithmetical operations performed with great accuracy.

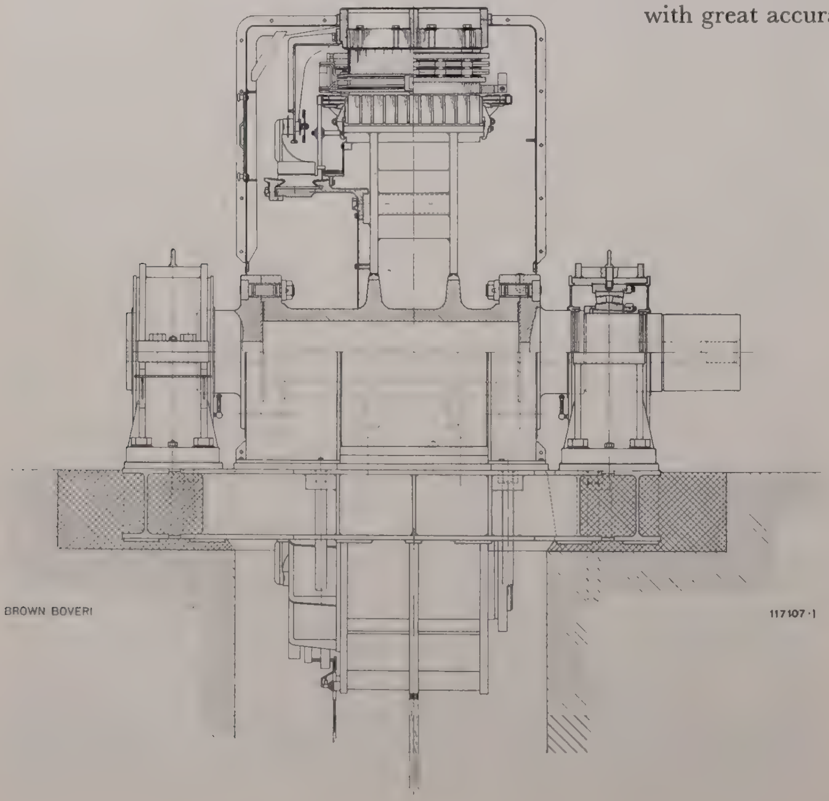


Fig. 131. – Reversing d.c. motor with self-aligning roller bearings, driving a blooming mill

Effective output 2900 kW, speed 0 ± 60/120 rev/min, cut-out torque 150 mt.

In industrial applications mainly the first two of the above ranges are utilized. The power engineering range is used above all for the control of electric drives. Here the main stress is laid on analogue techniques, operating with continuously varying quantities and principally employed in closed-loop control. On this account the range includes a versatile choice of elements for detecting the many different measured quantities (input units), for processing them to manipulated variable or controlled correction (control units), and for amplification (output or correcting units).

The *input units* convert the physical quantities, such as current, voltage, power, speed or angle of rotation, etc., into electric signals within a standardized range, which are then conveyed to data processing or control units, in the simplest possible case to a regulator.

The *control units* process these signals and produce a correction or manipulated variable. Depending on the nature of the task to be performed, these units contain elements with the properties of an amplifier, controller, non-linear elements, and so on, all of which possess the same standardized signal range. With a relatively small number of basic circuits it is possible to obtain all combinations likely to be required in practice for simple and complex control tasks.

The output of the control unit is the correction, which is amplified to the necessary power level in the *correcting units*. Passing through transistorized matching units, the standardized input signal acts on the various stages of the correcting units, such as mercury-arc rectifiers, thyratrons, semiconductor thyratrons, magnetic amplifiers and power transistors.

To augment the analogue elements of the power engineering range there are also a number of digital elements. With these it is possible to produce most of the simple logic circuits, for instance for simple interlocks, automatic operation or discontinuous intervention in the control loop. The maximum working frequency of this range was made 1 kc/s, which is generally sufficient for the applications referred to above.

As soon as open or closed-loop control systems are realized on a digital basis, such as in the numerical feed control of a machine tool, counting speeds become necessary which are well above 1 kc/s. In such cases the counting range is used, permitting a maximum working frequency of 100 kc/s for the digital elements. In this range the input, control and correcting units can be similarly combined, owing to the utilization of standardized signals. Simple adapting elements facilitate the inter-relation with elements of the other ranges.

The two other ranges, for tele-operations and computer applications, are mainly employed in fields described on pages 156 to 159 of this issue. In some cases they can render valuable assistance in augmenting an industrial installation.

Apart from the electrical standardization, the Brown Boveri electronic system is also based on standard constructional units. The printed circuit (Fig. 132) is the smallest "building-block", followed by the sub-unit (Fig. 133). The combinations of these with other larger or integral units, are accommodated in tiers of internationally standardized dimensions, which, in turn, are mounted in wall or floor cabinets (Fig. 134) or in switchboards (Fig. 135). Mounting on a hinged frame renders all parts easily accessible.

The above remarks only outline the principal features of the Brown Boveri electronic system for analogue and digital techniques. More detailed descriptions were given in a special number of the Brown Boveri Review (No. 10/11, 1960).

2. Rolling-Mill Drives

2.1 Reversing mills

With very few exceptions the main drive motors for blooming and slabbing mills have been fed from mercury-arc rectifiers, while motor-generator sets were used to feed the majority of the reversible auxiliaries. The reversal of the torque or flow of energy needed for accelerating or braking the motor employs the accepted principle of field reversal with controlled super-excitation, the armature merely being fed by the mutator in single-tank connection.

Fig. 136 illustrates the control room of a reversing mill installed in 1960, having a cut-out torque of 150 mt. This blooming mill is primarily employed for rolling high-alloy steels. The special requirements associated with rolling the ends of the blooms in two directions successively are admirably solved by an

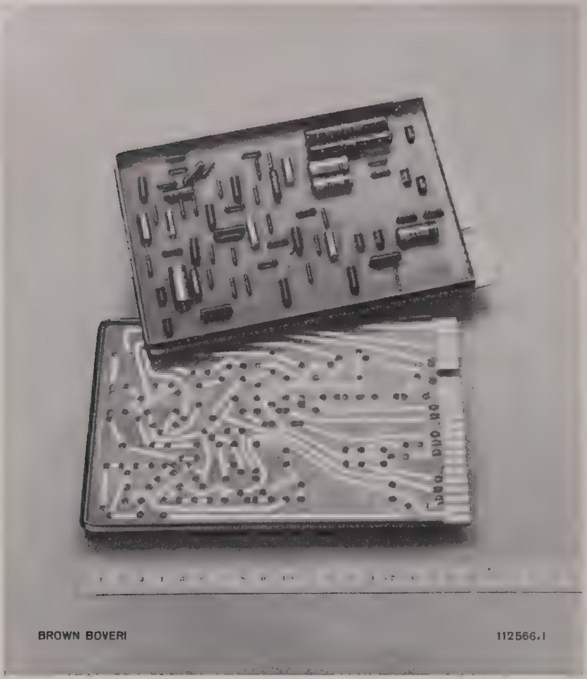


Fig. 132. – Printed circuit, the smallest "building-block" of the Brown Boveri electronic system

It is designed as a plug-in element and has gold-plated contacts.

electric drive with field reversal. The power required for this drive, as shown in Fig. 137, is split between a number of pumpless rectifier tanks, thus simultaneously solving the problem of a constantly running reserve capacity.

For large drives, particularly where the drive power is spread over two or three motors, or more, the use of sequential control for the rectifiers is

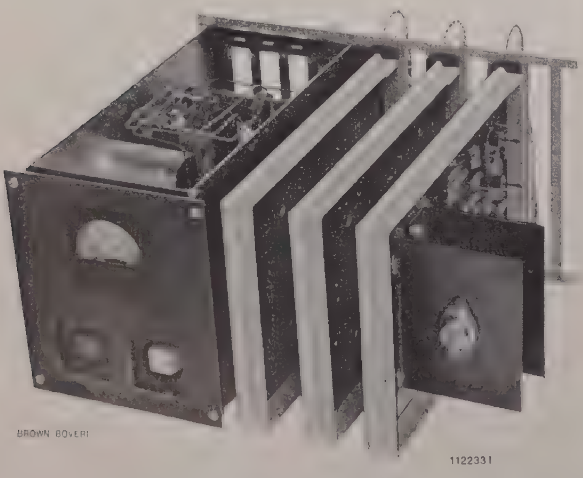


Fig. 133. – Standardized sub-unit ready for assembly in a tier

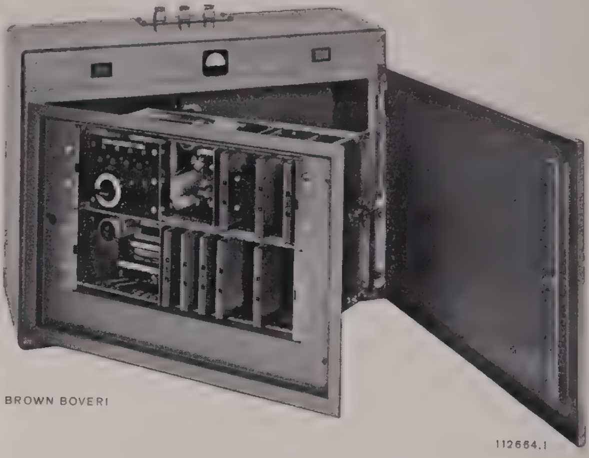


Fig. 134. – Small cabinet with hinged frame

The individual printed circuits and sub-units are accommodated in two tiers mounted in a hinged frame.

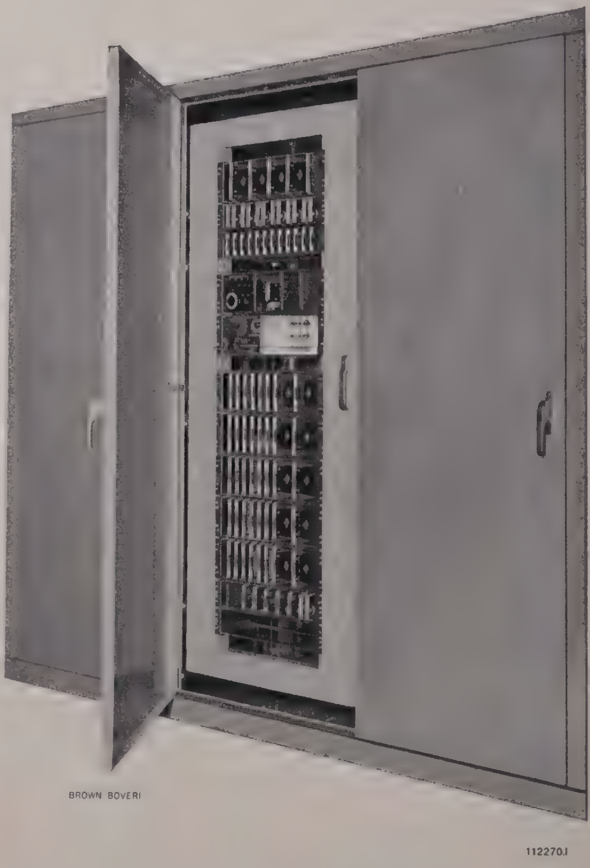


Fig. 135. – Switchboard containing a control section and hinged frames

Mounting the tiers on a common hinged frame affords easy accessibility at all times.

recommended. In this case the two groups of series-connected mutators are successively operated as rectifiers and inverters, so that the reactive load surges caused by the initial pass at low speed can be minimized. Brown Boveri, Mannheim, have recently commissioned a reversing mill drive with an effective power of 7000 kW and a cut-out torque of 300 mt, for which mutators with sequential control are employed.

Other reversing drives with an effective output of about 35 000 kW are at present on hand, for example two reversing motors designed as double-armature motors (Fig. 138) which Tecnomasio Italiano Brown Boveri, Milan, are building for a two-high mill in Belgium.

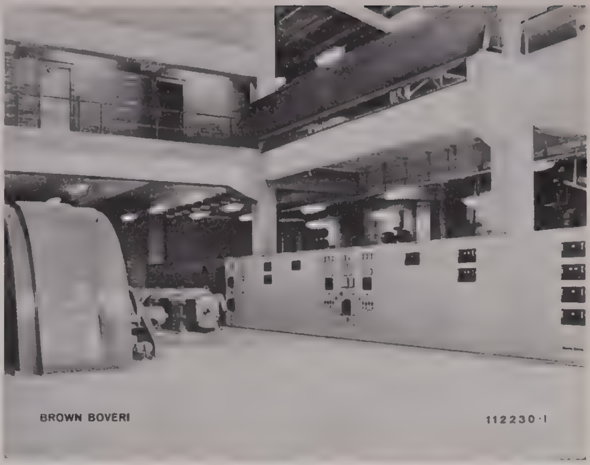


Fig. 136. – Modern switchgear and reversing motor for a blooming mill with a cut-out torque of 150 mt

2.2 Continuous rolling mills

In the last two years the Baden works alone has taken into service six continuous rolling mills with a total of 54 main drives and an effective output of roughly 26 000 kW. These are hot mills producing wire, rod, bar, semi-finished and broad strip steel. In accordance with the stringent specifications, all the drives are equipped with electronic control, thereby assuring the stipulated dynamic and static properties with maximum reliability.

When several motors have to be supplied from a rectifier-fed busbar system, a special quick-response system of voltage control is employed, which ensures that the load is evenly distributed between the various parallel rectifiers. The supply for the controlled fields of the motors is provided by a purely electronic element, requiring no intermediate amplifier. The elimination of all inertia in the correcting unit leads to extremely rapid response (Fig. 139).

Two installations deserving special mention are the continuous merchant mill in India, referred to on page 90, and a similar mill in South Africa, the drives for which are equipped with electronic control.

As was stated in the last review of progress,[7] the problems of complete automation of such plants by means of the specially created supplementary equipment had then already been solved; since then they have been improved. Special attention was devoted to the cutting section where, on the basis of carefully evaluated measurements from an existing cooling bed, methods were devised to obtain optimum accuracy in cutting the stock and in positioning it on the cooling bed. Of the automatic equipment supplied with the four cooling beds taken into service during the last two years, an excellent performance has been given by the electronic control system, and in particular the photo-electric relay specially designed for the rough-service conditions encountered in rolling mills (Fig. 140). The automatic control, on which the desired cutting length can easily be set, regardless of the rolling speed, by means of a potentio-

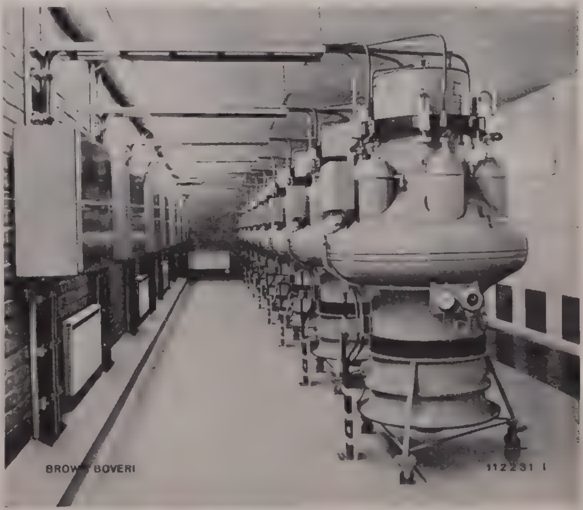


Fig. 137. – Pumpless six-anode mercury-arc rectifiers used to feed a reversing drive having a cut-out torque of 150 mt

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[7] See Brown Boveri Rev. 1959, Vol. 46, No. 1/2, p. 83–86.

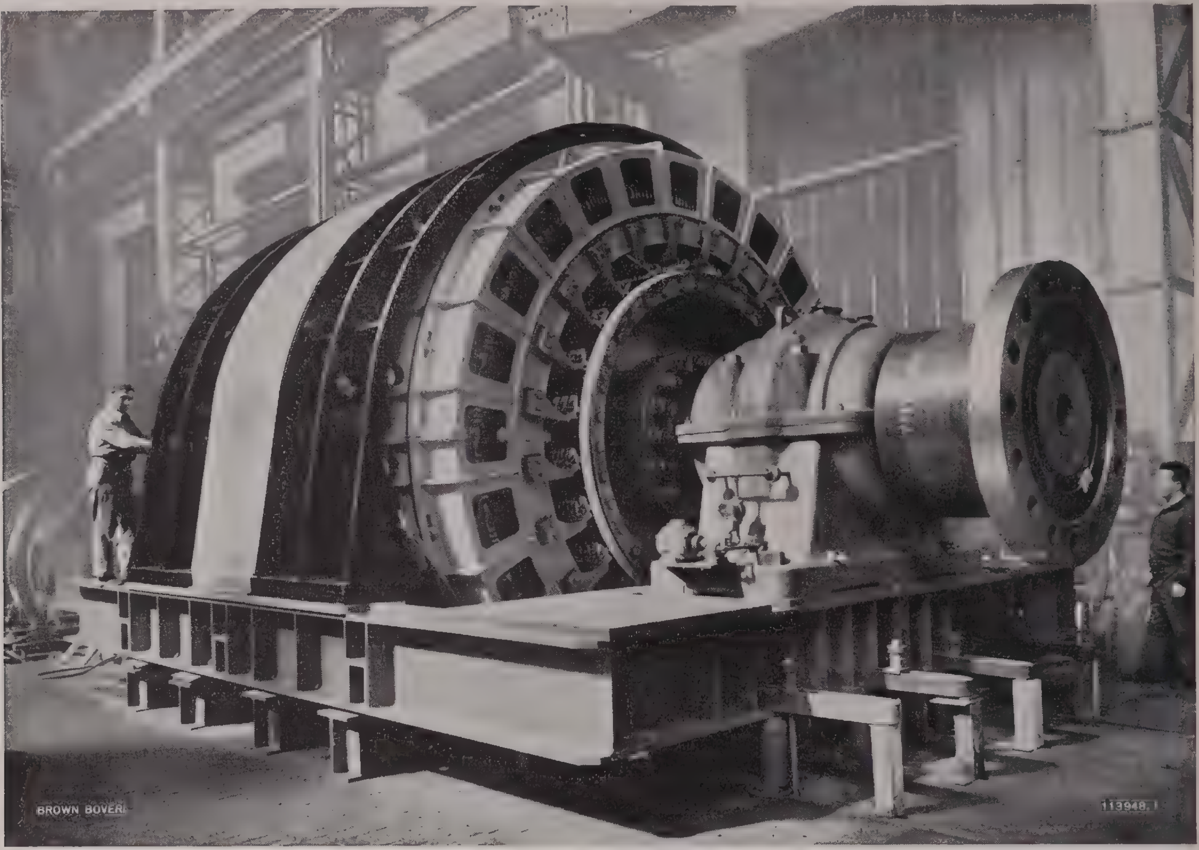

Fig. 138. – One of the two double-armature motors for a slabbing mill with a twin drive for a cut-out torque of 2×300 mt

Each of these motors is designed for an effective output of 4500 kW and a speed range of 40–80 rev/min. (Photo taken in the works of Tecnomasio Italiano Brown Boveri, Milan.)

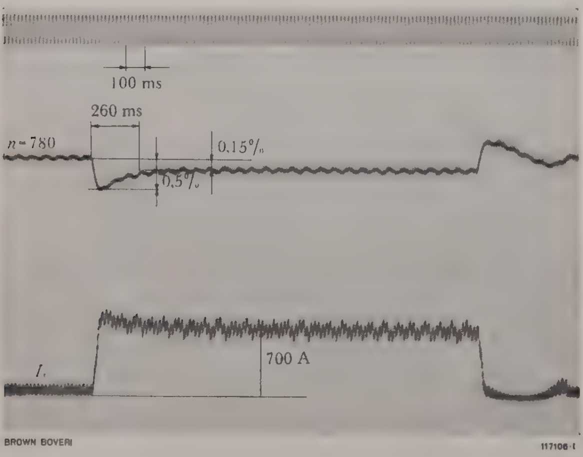

Fig. 139. – Current and speed of a field-controlled rolling-mill motor with direct field supply by thyratrons

Motor data:	Armature voltage	500 V
	Armature current I_A	1000 A
	Speed n	350/875 rev/min

meter, greatly simplifies the task of the operator. In addition to this, a measuring device has been developed, by means of which the cut lengths can be continuously and accurately measured. Furthermore, changes in the lead and the speed at which the stock leaves the final stand are indirectly supervised, so that changes in the roll calibre can be detected in good time.

Fig. 141 reproduces an oscillogram showing the current and speed of the oscillating ingot mould of a continuous casting machine, for which the Company supplied the three drives—for the mould, the pinch rolls and the straightening machine—with high-grade speed control and overriding current limitation. This machine proved very satisfactory indeed from the very start, both from the electrical and mechanical aspect.

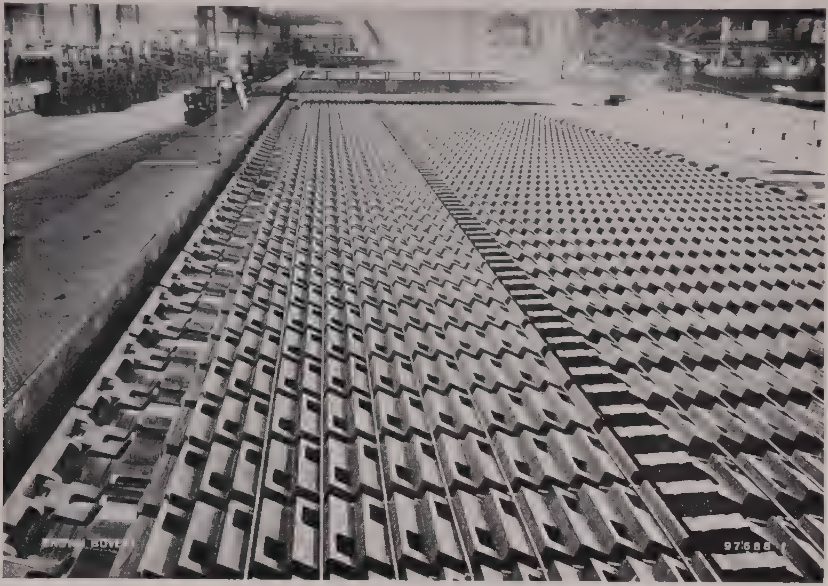

Fig. 140. – Photo-electric relay sensitive to infra-red radiation, used to control the cooling bed of a continuous rolling mill

2.3 Cold-strip mills

Counting the twenty-five cold-strip mills which Brown Boveri have equipped in the last two years, the total number of installations of this kind equipped by the concern as a whole since 1950 now amounts to roughly 100, with a total effective drive power of approximately 90 000 kW. These figures include drives for roughing and finishing mills, foil, skin-pass and Sendzimir mills for a variety of metals. The ratings of the motors range between 3000 and 60 kW for the rolling stands, and between 3000 and 5 kW for the coilers.

Whereas for small and medium ratings, motor-generators are still the main means of supply, greater use is now being made of mercury-arc rectifiers to supply drives of high rating. In accordance with the requirements of cold-strip mills, which have to accelerate and brake repeatedly, and therefore have continuously to reverse their torque, mutators in the single-tank connection have successfully been used to feed the armatures of two new main drives, with continuously controlled field reversal for changing the direction of the torque. In these installations the coiler drives are fed by rectifiers in an asymmetric anti-parallel connection.

As a result of the standardization of modern electronic control equipment, these have become more favourable in price for small and medium rolling mills and are now being used in the majority of installations. The quality of the control thus attained enables a single coiler motor to cover a wide tension range with short acceleration and braking times. This exerts a beneficial influence on the quality of the rolling stock, particularly during the accelerating and braking periods, and thus improves the overall output standard. At the same time the capacity of the installation is better utilized.

Fig. 142 shows the control room of a Sendzimir mill taken into service by the Company. The motors driving the coilers and the rolling stand are fed from motor-generators. The control equipment, including that for the coilers, is entirely composed of electronic elements. Thus it is possible to fulfil the extremely severe operational requirements and to attain the very short braking times in an emergency, required for Sendzimir mills and corresponding to the maximum output of the motors. In this rolling mill a pass-reduction computer is employed, which calculates the ratio of the thickness on the input side to that on the output side and effects the appropriate correction to the tension control—particularly the additional acceleration and braking components experienced by the coiler during the two periods.

The twin drive of a cold-strip mill, to which brief mention was made in the 1959 review of progress, has run very satisfactorily since and confirmed the advantage of having upper and lower work rolls of different diameters. The resultant elimination of

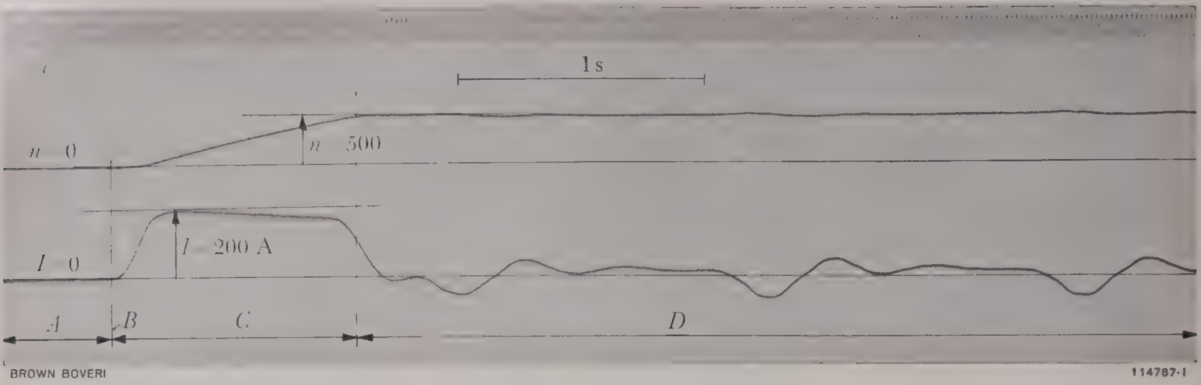

Fig. 141. – Current and speed during starting up the mould drive of a continuous casting machine equipped by Brown Boveri

the pinion stand with the twin drive, is rendered possible by the incorporation of an electronic system of balancing the current and speed, which can be ideally matched to the operating conditions.[8]

In this sphere of rolling mills close attention has also been devoted to the question of automation. The introduction of electronic control equipment provides a simple means of changing over to tension control following speed control of the coiler during introduction of the rolling stock. The transfer takes place smoothly for the strip, without the preset tension being exceeded. A system of thickness control, at present being manufactured, will shortly be placed in service. This will enable the rolling mill to correct slight changes in the thickness of the material by varying the rolling speed; the screwdown gear is not changed until quite a serious change in the thickness is experienced.

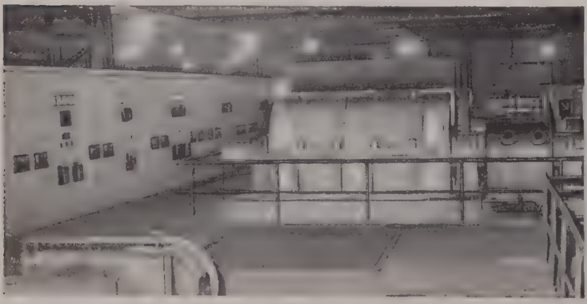

Fig. 142. – View of a 2500-kW Sendzimir rolling mill, the control system of which is equipped throughout with modern electronic Brown Boveri equipment

Supplied by our associates in France, the Cie de Construction de gros matériel "Electro-Mécanique", Paris

3. Mines Winders

The main features of development in the field of mines winders are the increasing use of three-phase induction motors, even for quite high outputs, and the automatic control of winding from intermediate levels.

The new universal controller makes allowance for both these trends. Like the winder controller mentioned two years ago, the universal controller produces an image of the pit-shaft, controls and supervises retardation in terms of the load, corrects controlling and supervisory elements on completion of a wind, and drives the miniature depth indicator. Beyond these, the new controller can also perform additional functions, which permit winding to and from intermediate levels without the need for any special auxiliary control equipment. By means of simple circuit modifications it is possible to wind automatically or semi-automatically from the pithead to any intermediate level, or between levels, with facilities for pre-selecting any desired winding programme with the corresponding terminus sequence. The universal controller was deliberately designed to be suitable for use for d.c. and a.c. winders. It can also be used with pulley winders, which are most widespread, or with drum winders.

The accuracy with which the new universal controller produces the image of the shaft, with 16 mm/m travelled at a depth of 1000 m, is very good which, in view of the increasing depths of modern mines, is important for the accurate and safe control of winders. With the aid of the principle of simulating the pit, as employed in this controller, it was possible to reduce the size and weight. Owing to the small space it occupies, the controller can be combined with the control unit and inserted as a single assembly in the control desk. The resultant increased concentration of the controls in a single space simplifies the operation and maintenance of the entire installation.

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[8] H. R. BILL: Regelmethoden bei Zwillingsantrieben für Warm- und Kaltbandwalzwerke. Elektrotech. u. Maschinenb. 1959, Vol. 76, No. 23, p. 563–74.

The increasing employment of the three-phase motor for pit winders has resulted in a rapid development of this kind of drive. As with all development work associated with the Brown Boveri programme for automatic control, special attention was devoted to the attainment of supreme accuracy with maximum reliability.

In order to adhere to the winding programme with great accuracy, a new liquid starter with pivoted electrodes has been devised. The range of adjustment of the resistance is of the order of 250 : 1. By this means the critical slip of the motor can be shifted over quite a wide range. A powerful hydraulic servo-motor is the actuator and produces very short adjustment times. The servo-motor itself is controlled by a highly sensitive dash-pot valve with a hydraulic amplifier. The combination of the various elements of the new starter produce a neat, compact design with effective, rapidly responding control of the current, using simple means. It has also proved possible to combine current control with elements of the Brown Boveri electronic system, easily augmenting them for speed control (Fig. 143).

The development of the new electro-pneumatic braking controller assures a high degree of safety in the sphere of a.c. winders. It can be universally employed to supervise the stipulated speed and can be utilized for all braking actions. With a.c. winders in particular it is employed to keep a check on the speed of the cage during the retardation period. For this the desired value of the speed is picked off the supervisory potentiometer of the universal controller, and the actual value from a tacho-generator. With an accuracy of ± 0·1 kg/cm^2 the braking controller applies a desired pressure proportional to the difference between desired and actual values of the speed to the braking pressure regulator of the Rapid brake. Acting through linkages and the brake blocks, the brake exerts a corresponding retarding torque on the pulley. If the winding speed exceeds the set value, the drive is securely braked until the desired speed is regained. The braking controller is fitted to all new a.c. winders supplied by Brown Boveri, with winding speeds exceeding 6 m/s.

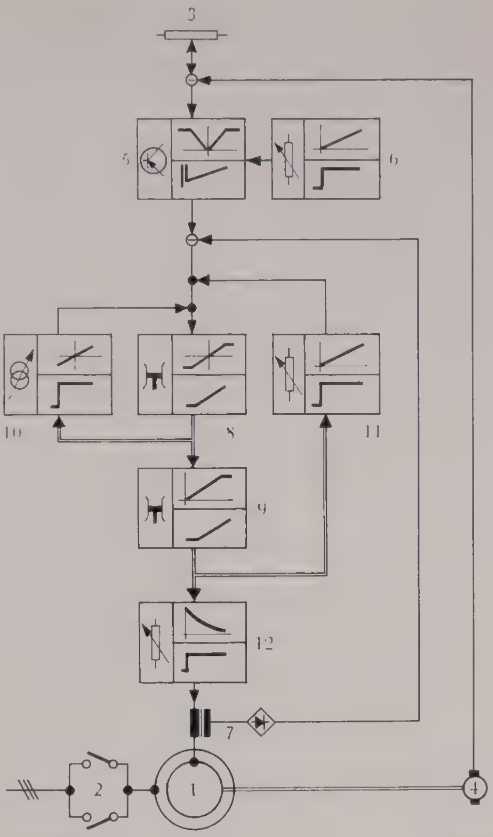

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Fig. 143. – Block diagram of the circuit of the speed and current control system for an a.c. winder

1 = Three-phase induction motor
2 = Stator reversing switch
3 = Reference potentiometer for setting the speed
4 = Tacho-generator for actual value of the speed
5 = Speed controller
6 = Setting current limitation
7 = Current transformer with rectifier bridge for actual value of current
8 = Hydraulic pre-amplifier (dash-pot valve)
9 = Servo-motor
10 = Proportional feedback
11 = Feedback element for compensation of non-linearities
12 = Liquid resistor

4. *Machine Tool Drives*

As ever, Brown Boveri drives for machine tools enjoy an excellent reputation. In the last two years a large number of interesting sets of Ward-Leonard equipment, some equipped with electronic control, have been ordered and taken into service. Automatic controls have also aroused the interest of the Company's customers. A striking technical novelty is the digital system described below.

4.1 *Digital controls*

Efforts to render the machining of small batches or individual complicated workpieces automatic have led to a heavy demand for very accurate numerical control systems for machine tools. Utilizing the elements of the "counting range" of the Brown Boveri electronic system it is possible to fulfil the varied requirements. In this respect we can look back on a number of years' experience in digital measuring and control techniques. The execution of numerous orders proved that even when great accuracy was not stipulated, the employment of digital methods, or a mixture of analogue and digital, yielded more advantageous solutions than previous methods.

4.1.1 *Positioning device*

The demand for a positioning device affording greater facilities for programming led to the development of a new unit based on the elements of the "counting range" of the Brown Boveri electronic system. The measuring system which proved successful in the former design has been retained, namely the transmission of straight-line motions by means of a rack and pinion to a photo-electric digitizer, in which pulses are counted. This new device can operate at feed rates up to 15 m/min with a resolving capacity of 0·01 mm. There is no limit to the distance which can be measured. The position to which the tool must run can be given by a punched tape or by manually-operated switches. The control unit of the device automatically determines the position from the input desired value, and the distance and direction to be travelled from the momentary actual value, controlling the acceleration and retardation of the feed so that the desired position is reached in the shortest possible time.

The unit can be expanded to cope with any number of co-ordinates, and can thus be employed on complicated machines having several feed motions.

Punched tape can be used, not only to give the positional values, but also all subsidiary commands relating to the feed rates, gear stages, cooling and lubricating media, and so on. Thus long and complex sequences of operations can be performed automatically. But it is also possible to give the positional values for individual operations by means of manually-operated decade switches, should difficulties in machining necessitate additional operations, or if it is not worth making a special punched tape.

All the controls needed for the programme are arranged on a control unit, separate from the circuits accommodated in the cabinets. This control unit also contains luminous projection indicators on which the momentary position is indicated numerically. The unit can therefore be employed for measuring all kinds of distances.

4.1.2 *Ram drive of a large gear shaper*

The gear shaper illustrated in Fig. 144 is used to make large gear-wheels up to 6 m in diameter and weighing up to 50 t. On it the ram is moved via a spindle driven by a Ward-Leonard d.c. motor. A new control system was devised for this machine. The speed of the ram is infinitely variable in the range 1 : 10. The frequent reversal (up to 6000 times per hour) made it necessary for the control to be contactless. The point of reversal, once it has been set, must be constantly maintained, regardless of any change in the speed of the ram, and the braking distance kept as short as possible.

In this device the ram movement is transmitted electrically to a control cam in the control desk, which has thin metal vanes instead of the usual dogs. These vanes move over the adjustable oscillator position indicators, without touching them, and generate control pulses which notify the reference input unit of the passage of the vane. To set the desired point of reversal a position indicator is adjusted to the point in question, for each direction of travel; the signals they emit cause reversal to take place. Beforehand, the vanes pass another position indicator, whose setting corresponds to the position of the ram at which braking must commence at the maximum speed of the ram, in order that the respective reversal point is approached at a sufficiently low speed. At lower ram speeds the braking action automatically commences sufficiently long after the braking signal to ensure that the point of reversal is always attained under the same conditions.

The positioning signals, besides being conveyed to the reference input unit, are also applied to the programming unit. There they are logically related with the machine commands and the acknowledgement signals in a number of interlocking circuits, in such a manner that the high degree of reliability is attained, as regards both the operation of the machine and its control.

In a somewhat simplified form a system of this kind can be used for planing machines; it renders valuable service in situations where stress is laid on ease of adjustment of the point of reversal, as well as freedom from maintenance, and replaces the conventional rapid-reversing drive.

4.1.3 Digital feed control for planing machines

On planing machines it is common practice to derive the tool feed from the table motion by means of a ratchet-gear and transmit it to the toolholder by rodding and spindles. The weakness of this system is neatly circumvented by the application of counting techniques. The carriage spindle is driven by a d.c. or twin-stop motor, required in any case for the high-speed traverse motion and for setting up. Coupled to the spindle is a contactless pulse generator which emits a pulse for every 0·1 mm travelled by the toolholder. If the table reversal control gives a command for the feed to advance one step, the pulses are added in a counter. As soon as the latter reaches a number preset on a manually-operated decade switch, the feed motor is switched off and the counter reset to zero. If the tool slightly overruns the new position when the counter picks up, the latter stores the corresponding pulses, debiting them against the next tool advance; next time the motor is switched off that much earlier. Thus overrunning is compensated for with every step. The full feed distance is accordingly covered in the foreseen number of steps, maintaining constant steps. It can also be preset by a decade switch. As soon as the full distance has been covered and the last chip removed, the machine is stopped. With this arrangement it is even possible to leave a machine working overnight once it has been adjusted and set in motion.

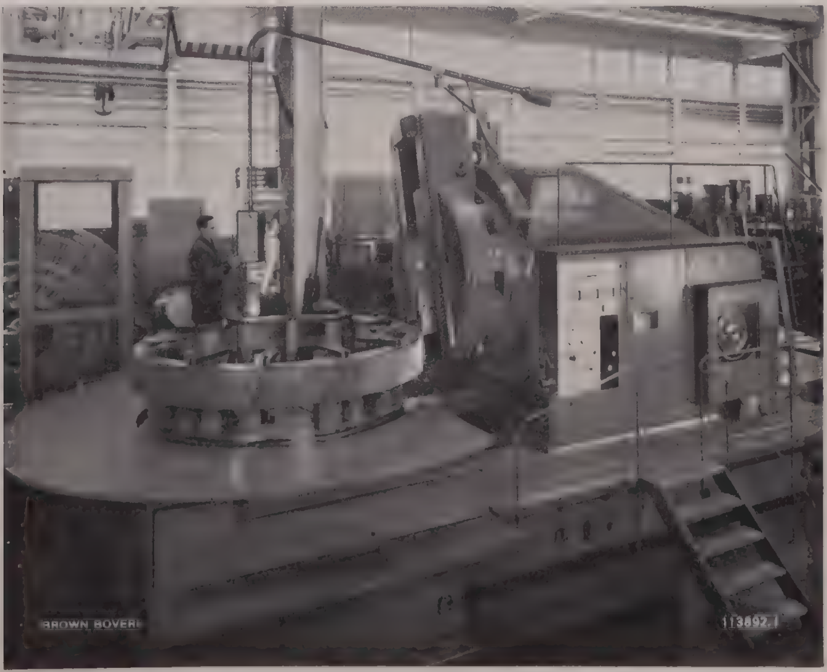

Fig. 144. – Ram drive of a large gear shaper

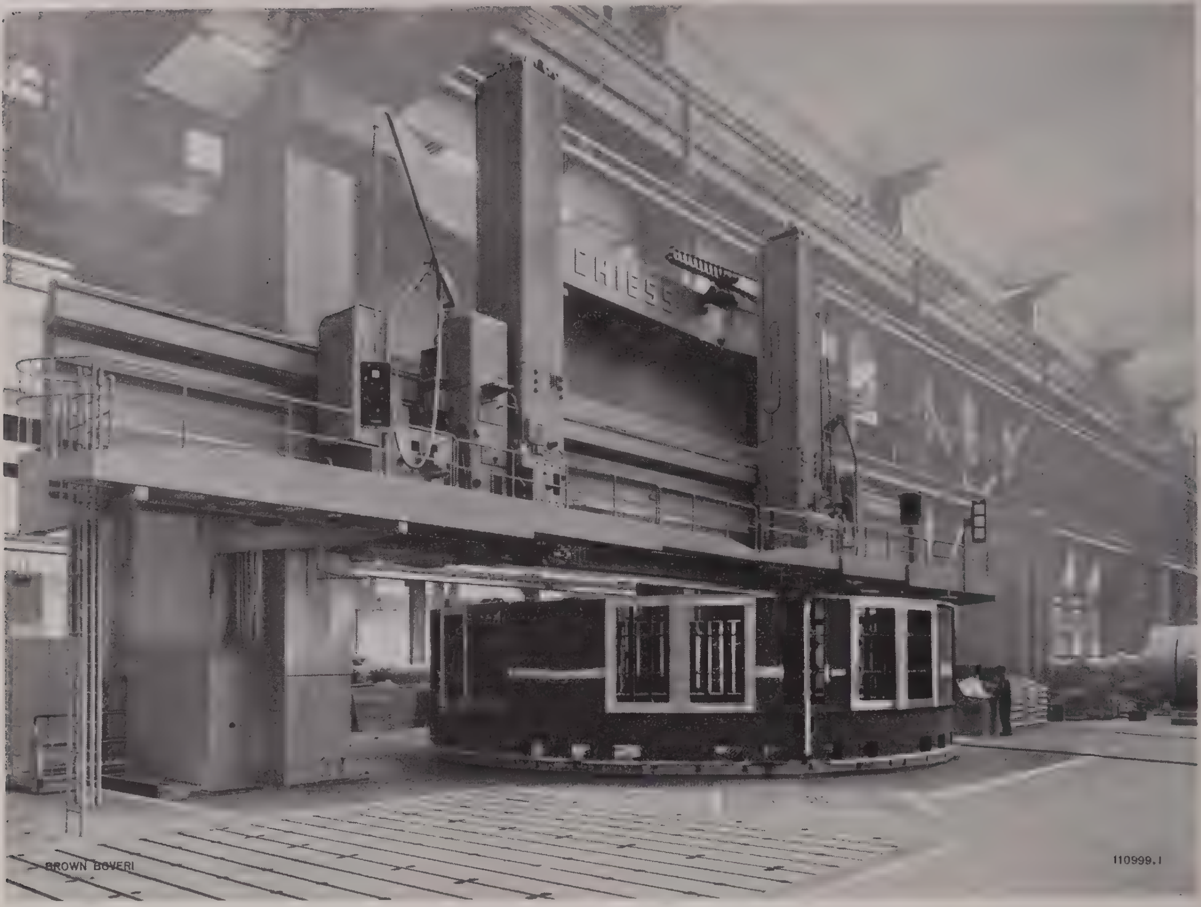

Fig. 145. – Large vertical lathe (built by Schiess, Dusseldorf, Germany)

The stator of a hydro-electric generator is being machined on the annular face-plate with an outside diameter of 10 m.

Maximum turning diameter	14 m	Speed of annular face-plate	0·08–10 rev/min, infinitely variable
Maximum turning height	6·1 m	Speed of inner face-plate	0·19–24 rev/min, infinitely variable
Diameter of the annular face-plate	10 m	Maximum admissible load on annular and inner face-plates	270 t
Diameter of the inner face-plate	5·5 m	Weight of machine	appr. 800 t
Ram extension	3·7 m		

4.2 Electric drive of a large vertical lathe

The drives of very large, modern machine tools often pose a number of special problems which can only be solved by adopting different control systems. An example of this is given below, considering the drives of the face-plate and feed of a large vertical lathe (Fig. 145).

A Ward-Leonard system was chosen for the main drive; in addition to providing facilities for speed variation, it also permits electric braking, which is very important indeed when such heavy rotating masses are involved. The system of speed control has to attend to the maintenance of constant speed when the load fluctuates rapidly, such as occurs when cutting is interrupted, as well as controlling the current during braking and accelerating. It must be possible to preset the speed. For facing, a simple device must permit control to constant cutting speed.

In order to fulfil these varied requirements as well as possible, an electronic control system with a thyratron output stage was chosen to excite the Ward-Leonard generator direct (Fig. 146). To have the maximum power of the machine available over as wide a speed range as possible, the motors are equipped for field weakening.

On a machine of this size the feed drives have to be co-ordinated with the main drive, so as to obtain a constant feed travel per revolution of the face-plate, regardless of its speed. Mechanical transmission by splined shafts is uneconomical for such machines; normal selsyns are inflexible and permit only a stepwise change in the feed rate with speed-change gearing. Therefore a variable-speed d.c. drive was selected for the feed. The desired-value voltages corresponding to the speeds are gained from tacho-generators coupled with the face-plate. Thus the feed motors are co-ordinated relatively with the face-plate drive. By means of a voltage divider on the tacho-generator for the desired-value voltage, the relationship between the speeds of the face-plate and the feed can be varied within the graduation permitted by the gear stages, thereby allowing the most favourable feed rate to be set at any given time. A small additional circuit allows the feed motors to be accelerated and stopped at a constant rate, thus permitting direct-on-line starting.

The controls are mounted on a desk and two pendant stations. The latter contain only those push-buttons and potentiometers which are continually required for controlling the face-plate and feed in operation. All other elements, such as the buttons for the motor-generator sets, the cross-beam traverse, the crane, the selectors for the face-plate gear stages, supervision of the oil pressure, bearing temperature, etc., are all accommodated in the desk. Naturally it also contains the other elements for controlling the face-plate and feed. The consistent employment of push-buttons with built-in pilot lamps, together with striking symbols and a skilful arrangement of the controls, enables the machinist to assess the state of the machine at a glance, as well as simplifying operation.

5. Drives in the Paper Industry and Printing Works

5.1 Paper-machine drives

The situation in the paper machine field continues to be dominated by the increasing production speeds, as well as greater widths. As regards their operation and speed control, these add to the problems which have to be solved by the suppliers of the electrical equipment.

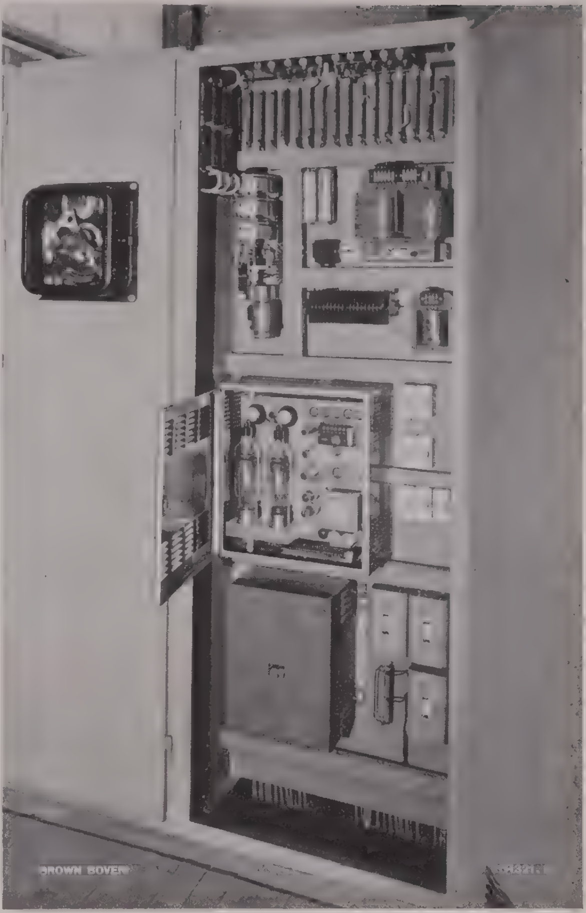

Fig. 146. – Thytron Ward-Leonard control for a variable-speed drive on a large Schiess lathe, drive rating 2 × 130 kW

The electronic control system attends to the regulation of the voltage of the Ward–Leonard generator, while the sector regulator (left) weakens the field of the two variable-speed motors via an intermediate machine.

Brown Boveri sectional drives with separate unit-connected generators, as employed for high-speed newsprint machines (Fig. 147), comply admirably with these strict conditions.[9] To judge by the operational experience gained in the last two years with the drive of a Beloit newsprint machine with a wire

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[9] E. ANDRES: The problems of regulating high-speed paper machines. Brown Boveri Rev. 1957, Vol. 44, No. 11, p. 510–4.

E. WANNER: Control of the individual sections of paper-machine drives. Brown Boveri Rev. 1960, Vol. 47, No. 8, p. 489–500.

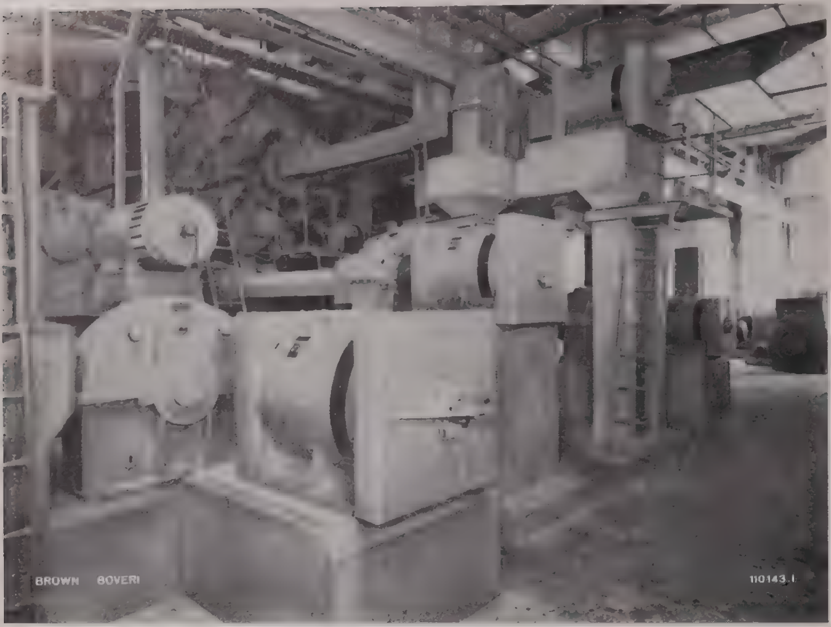


Fig. 147. – View of part of the driving side of a newsprint machine with a top speed of 750 m/min

In the foreground is the 380-hp motor driving the forward drive roll of the wire. The ratio of the power of the motors driving the couch roll and the forward drive roll is controlled by a vacuum-meter. On the right-hand edge of the picture is the motor rated 800 hp at 1000 rev/min which drives the driers.

width of 7366 mm and a speed range of 250–750 m/min, it has been possible to raise the speed up to 630–680 m/min while maintaining a good working efficiency. For modernization and increasing the speed of an older machine, the same customer ordered an exactly similar drive. Another sectional drive of this kind is running satisfactorily, and a third is being erected; two more are due for installation in the course of 1961.

Trials with the control gear for the largest and fastest newsprint machine in Europe have been completed; this machine is being installed by A. Ahlström Oy, Warkaus, Finland. The data of the machine, which was built by J. M. Voith, Heidenheim, Germany, are: wire width 8300 mm, speed 400–900 m/min. The twelve Ward-Leonard generators, with a combined output of 4500 kW, feed a total of 18 motors. This includes the stock-pump

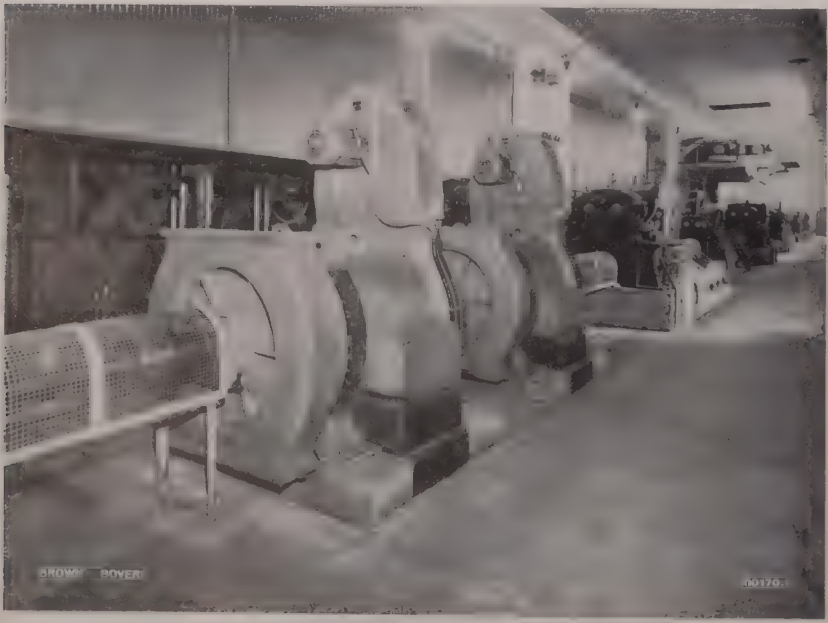


Fig. 148. – Drive of a newsprint machine by means of a longitudinal transmission for a maximum working speed of 600 m/min

Each motor develops 650 kW at 1200 rev/min. They can be inserted at any convenient point in the transmission system. They are supplied by two d.c. generators driven by a synchronous motor.

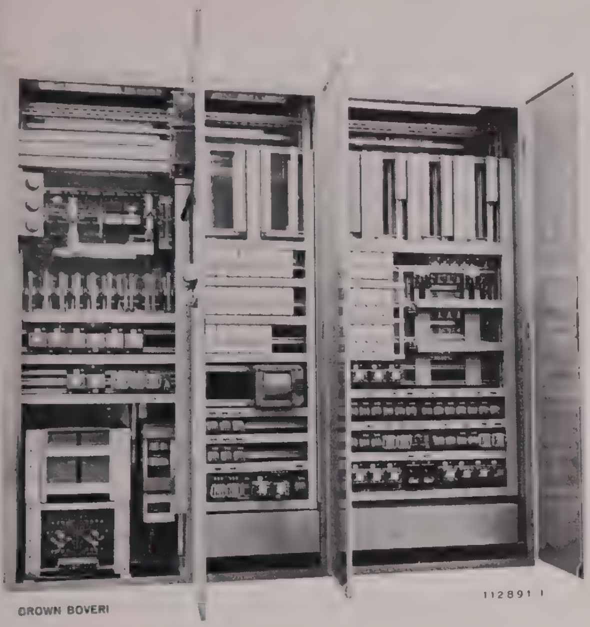


Fig. 149. – Control cabinet of the sectional drive of a rotary printing press

The left-hand section of the cabinet contains the magnetic amplifier control system. The right-hand sections are for the auxiliaries. At present the installation only has two motors; subsequent extension is planned.

motor but not the drives of the suction pumps. The generator fields are fed by high-powered, reliable Brown Boveri magnetic amplifiers. The duties of control and matching to the electronic controllers are performed by intermediate amplifiers containing transistors. The well-tried system of cascade control circuits is retained, the speed control circuit with proportional-integral-derivative action (PID) being superposed on an angular control circuit with integral action. These elements produce a control system with a high dynamic and static response. A further feature is that all twelve control sets are composed of identical elements, which greatly simplifies the question of spares.

During the last two years several paper machines have been equipped with longitudinal main drives (Fig. 148) and helper drives. The power of the main shaft drive without the helpers may amount to 1760 kW on large machines; this is preferably split between two motors. The speed of such machines can increase to 800 m/min with wire widths of 6800 mm. The stipulations regarding the accuracy and constancy with respect to time, while maintaining high quality of control, have led to new solutions being sought. Using standardized elements an expedient, reliable circuit was devised, fulfilling the stipulated conditions. By utilizing the principle of cascade voltage and speed control circuits it was possible to obtain short control times. The effects of mains fluctuation are thereby minimized. This is particularly admired by all manufacturers who value paper having a uniform specific weight.

At the moment six orders are on hand for drives of this kind, three being already in the erection stage. The simple, neat layout of the circuit and its reliable performance make this system ideal for use with longitudinal drives of paper machines.

5.2 Drives in printing works

Nowadays, in addition to the three-phase shunt commutator motor which for a long time dominated the field of drives for rotary printing presses, it is quite common to find variable-speed d.c. motors. Two examples of this are now described.

Sectional d.c. drive with Ward-Leonard control

Brown Boveri were given the task of providing the drive for a large newspaper press, with six motors, each having an output of 90 hp. It had to be possible to operate these motors separately, or in groups of from two to six, coupled through a longitudinal shaft with provision for uniform load distribution. In this case variable-speed d.c. motors with Ward-Leonard control were selected, each motor having its own Ward-Leonard generator, a system which has given excellent results with rotary presses having two or three machines (Fig. 149). The speed is kept constant with great accuracy while threading in the paper and during operation, as a result of employing magnetic amplifiers for the speed control. For parallel operation a uniform load distribution is assured by a control system which balances the currents. Electric braking is also possible without requiring any additional equipment. The space occupied by the converters was kept small by employing the modern vertical type. With this drive it is possible to carry out the following actions: Inching and threading-in at about 1/60 of the full speed;

eleration and retardation by means of a remote-controlled motor-driven potentiometer; emergency braking with constant retardation in a few seconds. A mimic diagram provides a constant picture of the state of the various couplings and the associated coupling switches, thereby preventing possible faulty manipulation.

Rotary press driven by rectifier-fed d.c. motors with magnetic amplifier control

The tremendous progress which has been made in the sphere of semiconductors has made available silicon diodes for high inverse voltage and service currents up to several hundred amperes. The diode, which in itself cannot be controlled, is rendered controllable by employment in conjunction with a magnetic amplifier. During the last ten years the magnetic amplifier has also made astounding progress.

A good example is a control unit for an output of 40 kW, used for the drive of a rotary press. The magamp-rectifier set with a rating of 50 kW is connected to 380 V, and feeds the d.c. motor direct. By means of a control system comprising elements of the Brown Boveri electronic system described earlier, the speed can be kept to within 1 % over a range extending from 300 to 1500 rev/min. For threading-in the speed can be reduced to 30 rev/min.

The controller and the associated equipment, such as the stabilizing filter, mixing circuit for the desired and actual value, as well as the stabilized power packs, are composed of printed circuits mounted in tiers. The manipulated variable at the output of the controller acts on the magnetic power amplifier through a transistorized preliminary stage and an intermediate magnetic amplifier. An internal voltage regulation in the intermediate and output stages renders the drive insensitive to mains fluctuation and linearizes the characteristic of the output stage. Since there is no excitation time constant to be overcome, the system functions very rapidly, thereby improving the quality of the control.

IV. ELECTRO-HEAT

A. Electric Furnaces for Foundries and Metal Industries

1. Arc Furnaces

Business has developed most encouragingly in the field of arc furnaces, especially as regards shipments for overseas territories, such as India, Central and South America. As a result of the good performance of the first arc furnace with a capacity of 3–4 t installed in Central America, a number of subsequent orders have been received for this part of the world. The initial fears of the electricity authorities in San Salvador that the operation of arc furnace plants would adversely affect the lighting proved to be unfounded, as no disturbing influence was detected after the furnace had been commissioned. This clearly demonstrates that, when such installations are correctly dimensioned and planned, it is possible to avoid unpleasant repercussions on the supply network.

In the summer of 1960 the Empresa Siderurgica of Medellin (Colombia) took into service an arc furnace with a capacity of 6–8 t, for top charging, with a connected load of 3000 kVA (Fig. 150). This is installed in the customer's Medellin works; for the Bogotá works of the same customer a 4–5-t furnace for top charging will be commissioned early in 1961, with an input of 2750 kVA.

Shortly after the production of electric furnaces was commenced in Brazil, our concessionaires in Osasco (São Paulo) received orders for six installations with furnace capacities varying between 1·5 and 6 t, two of which are already in operation.

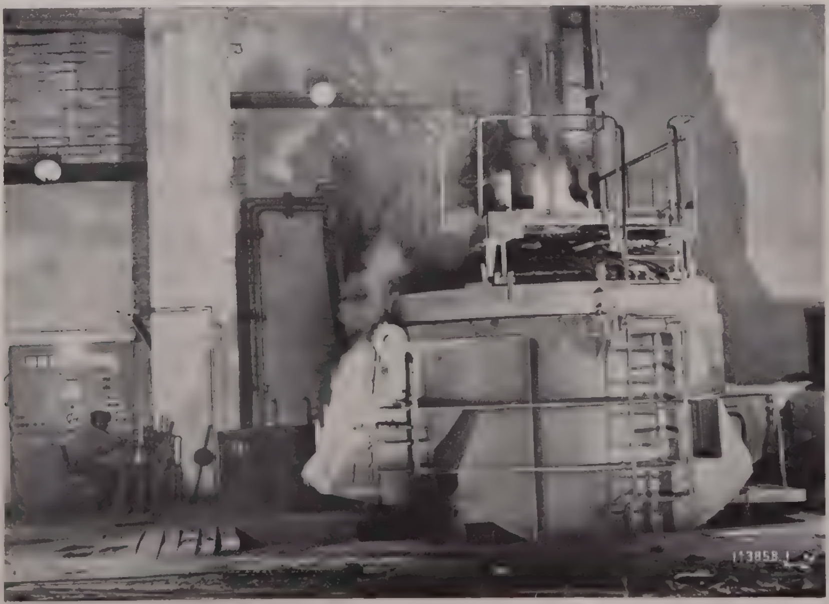


Fig. 150. – Arc furnace with swivelling roof for top charging installed at Empresa Siderurgica S.A., Medellin, Colombia

Capacity	6–8 t
Input	3000 kVA

An important repetition of an order referred to in the last review of progress was the contract for supplying a 10–12-t furnace with an input of 5200 kVA for the new foundry of Sulzer Bros., Winterthur.

2. *Induction Furnaces*

2.1 *Mains-frequency melting furnaces*

The advantages of mains-frequency induction melting furnaces for grey-iron and light-metal foundries are being recognized by an ever-growing number of customers. A Swiss ironworks, which has been operating a 6-t holding and superheating furnace for grey iron with an input of appr. 700 kW since 1958, recently ordered a 4·5-t induction melting furnace with an input rating of 800 kW at 500 V, 50 c/s; this installation was commissioned in December 1960.

The Japanese firm Shin Mitsubishi took delivery towards the end of 1960 of a 4·5-t induction melting furnace with an input of 800 kW, 500 V, 60 c/s, and an 8-t melting furnace with the same rating. Both furnaces are to be employed for melting grey iron.

The induction melting furnace which has been in service for about three years with Aluminium Laufen AG., Switzerland, with a capacity of 1200 kg of aluminium, has been running very satisfactorily. In the meantime this customer has ordered a 2·2-t furnace with an input of 480 kW at 500 V, melting output 890 kg/h and an energy consumption of 540 kWh/t. This will be installed in the new aluminium plant and is due to come into service in the spring of 1961.

A second 800-kg mains-frequency melting furnace for cast steel has been sold to India. For Chile two 1-t furnaces for holding and superheating bronze are at present being constructed.

In 1960 a total of five 12-t induction furnaces were commissioned for holding grey iron in Italian foundries. These were repeat orders placed as a result of the good performance of furnaces ordered previously. The trend towards larger furnace capacities is also noticeable with mains-frequency furnaces. It is planned to build furnaces for up to 30 t, based on grey iron.

2.2 *Medium-frequency melting furnaces*

As a result of the excellent experience gained with the furnaces with capacities of 250 and 500 kg, supplied to the Aciérie d'Hirson three years ago, where they are used for the production of manganese steel, two further furnaces of the same sizes have been ordered in the meantime.

An order from Motomecanica S.A., Buenos Aires, is at present being executed, calling for medium-frequency furnaces with capacities of 250 and 750 kg for melting steel. The power of this installation is 250 kW at 1000 c/s. Later, when the plant is extended, the power for the larger furnace will be increased to 500 kW.

In the spring of 1961 a medium-frequency installation will come into service at the works of Georg Fischer, Schaffhausen, Switzerland. It comprises a 1500-kg furnace with an input of 800 kW, 1025 c/s, two 500-kg units for 400 kW and one 100-kg unit for 200 kW, all for the same frequency. Their purpose is melting steel (Fig. 151). The medium-frequency converter installation comprises eight vertical units, each having an output of 200 kW (Fig. 152). The arrangement of these is such that four are permanently allocated to the 1500-kg furnace and two pairs for each of the 500-kg furnaces. By means of a suitable arrangement of the switchgear it is possible to connect one of these converters to feed the 100-kg furnace. It is thus possible to melt simultaneously with the 1500-kg and the two 500-kg units, with the 1500-kg, one 500-kg and the 100-kg furnace, or with both 500-kg and the 100-kg furnaces, as required.

3. *Hot-Galvanizing Baths*

Protection of steel against corrosion, especially for outdoor installations, becomes increasingly important. Practice has proved that hot-galvanizing is superior to any other method of corrosion protection. This is reflected in the fact that new galvanizing plants with larger zinc-baths are continually being

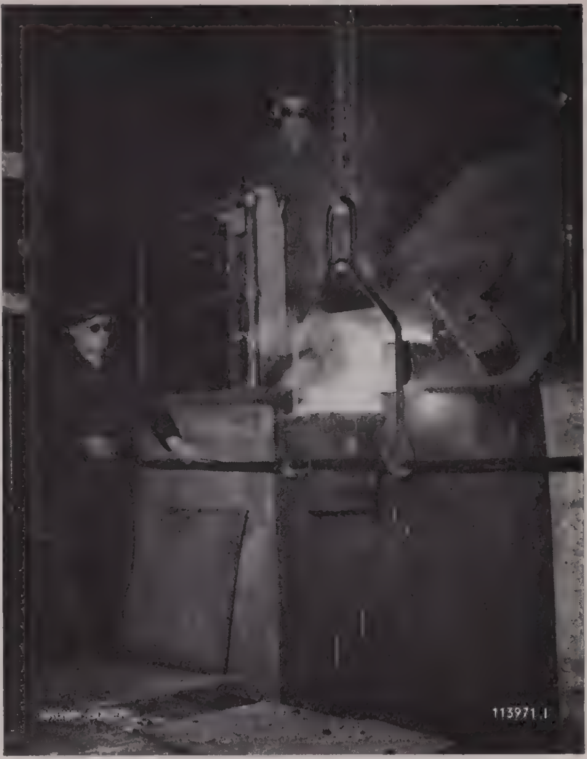


Fig. 151. – Medium-frequency induction installation for melting special steels at Georg Fischer, Schaffhausen, Switzerland

Comprising:

1500-kg furnace, 800 kW, 1025 c/s
2 × 500-kg furnaces, each 400 kW, 1025 c/s
100-kg furnace, 200 kW, 1025 c/s

In the picture one of the 0·5-t furnaces is being poured.

installed. Electrically-heated galvanizing baths offer the great advantage over fuel-heated plants that, owing to the more uniform heating and much lower temperature peaks, the life of the bath is greatly prolonged, which of course improves the economics of the installation.

In the summer of 1960 the largest zinc-bath in Europe, measuring 15·1 m long, 2 m deep and 1·2 m wide, corresponding to a content of 250 t of zinc, and having an input of 1020 kW, was taken into service at the Verzinkerei AG., Aarberg, Switzerland (Fig. 153).

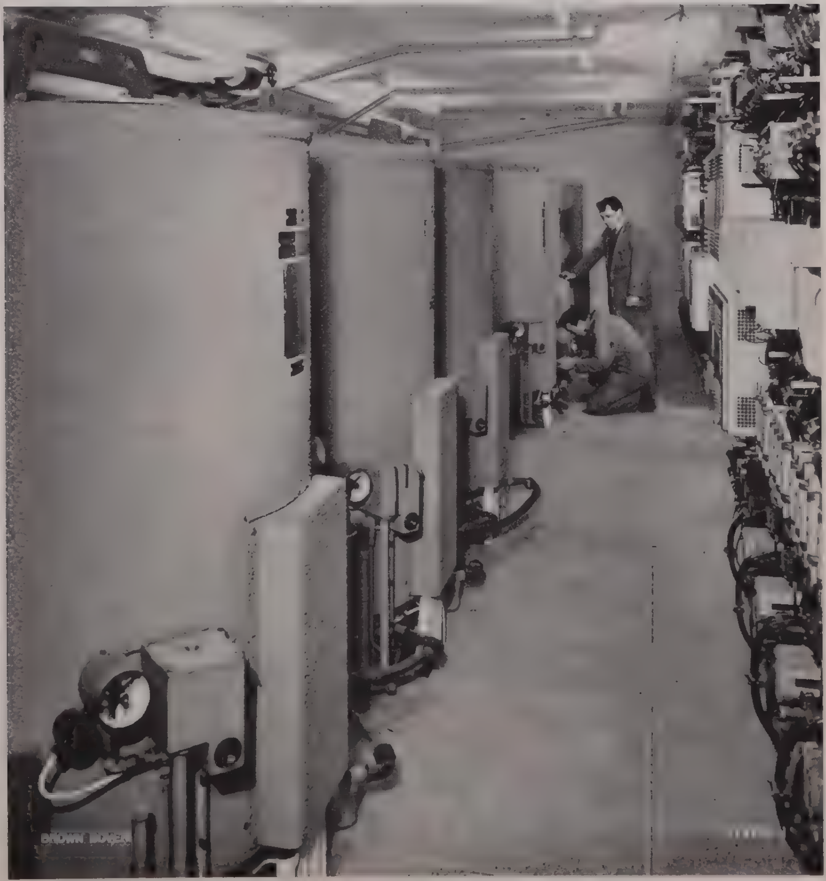


Fig. 152. – Medium-frequency converter installation for furnaces

with eight 200-kW converters for 1025 c/s which can be connected to the various furnaces, as required.

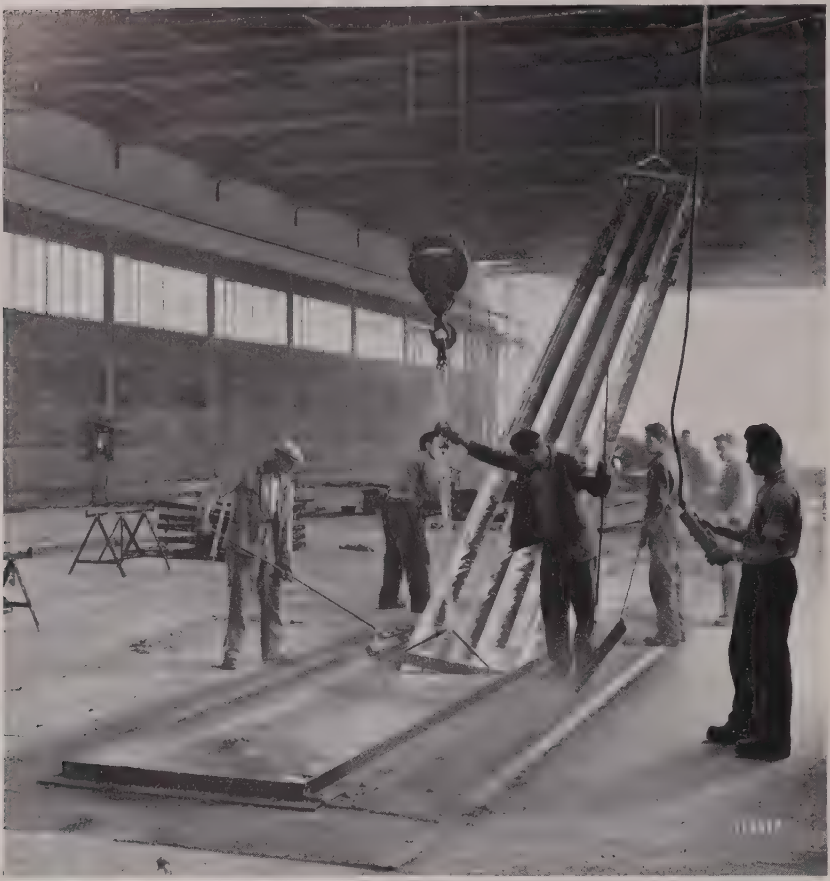


Fig. 153. – Electrically heated hot-galvanizing bath at the Verzinkerei AG., Aarberg, Switzerland

Input 1020 kW.

Bath dimensions:

15·1 m long, 1·2 m wide, 2 m deep, holding appr. 250 t zinc.

This is the largest electrically heated galvanizing bath in Europe.

B. Electric Furnaces for Other Industries

Ceramic Kilns

Early in 1960 Pargas Kalkbergs AB placed an order with the Company for a double tunnel kiln 73·4 m long, for their tile-works at Åbo in Finland. This kiln, which has a rated input of 705 kW, will be used for biscuit firing of wall-tiles at a maximum temperature of 1250 °C and for glost firing at a maximum of 1100 °C. This order was secured in the face of sharp competition because our guaranteed current consumption was better, resulting from the employment of a special patented control system. This installation is due to commence operation in the early part of 1961.

The excellent experience gained with a tunnel kiln 56·6 m long, which has been running since 1954, firing insulators at a maximum temperature of 1300 °C, induced the Norsk-Technisk Porseleinsfabrik in Frederikstad, Norway, to place an order in 1960 for a new, 61-m long tunnel kiln. This will have an input of 450 kW and will be used for firing insulators at 1400 °C in a reducing atmosphere, the output of the kiln being given as 3400 kg in 24 hours.

C. Induction Heating

1. The New Brown Boveri Induction Heating Laboratory

Experience having proved that r.f. generators can only be sold successfully when there are adequate facilities for investigating problems of a technical nature associated with the working process, for which the generators are employed by the customers, Brown Boveri established some years ago a special laboratory for dealing with customers' problems. Here experimental work is carried out on induction heating with medium frequencies, as well as radio frequencies. This small-scale establishment has now been augmented by a new, large laboratory equipped for investigations into m.f. and r.f. heating processes. Among the duties of this laboratory are the investigations into all problems of a metallurgical nature, or connected with the working process. These include:

- Full or partial pre-heating and heat treatment,
- Surface or complete hardening of steel parts, at rest or in motion,
- Melting and sintering processes,
- Soldering, brazing and welding processes.

To these may be added the testing of charging machines or complete installations consisting of a generator and charging machine. Finally this laboratory has prepared a detailed card index of all available information on the subject for promoting an exchange of views between all interested bodies, particularly within the Brown Boveri concern.

A further important duty of this laboratory concerns basic research in the widest sense, in contrast to the special tests undertaken at industrial frequency by the Company's well-equipped laboratory in Dortmund, Germany.

For the execution of the above-mentioned duties the new laboratory is equipped with at least one of each batch-produced m.f. or r.f. generator and/or charging machine, of the latest design. Thus the laboratory serves at the same time as an exhibition in which each object can be demonstrated in action.

Fig. 154 shows the four m.f. converters installed in a separate cabin; they are rated 200 kW at 1 kc/s, 120 kW at 2 kc/s, 100 kW at 4 kc/s and 50 kW at 10 kc/s, respectively.

As regards r.f. generators, the equipment includes the 100-kW, 500 kc/s unit visible on the left in Fig. 155, also a generator rated 10 kW at 2–2·9 Mc/s, two units each producing 25 kW at 1–2 Mc/s and, finally, the two generators illustrated in Fig. 156, rated 4 kW at a frequency of 3 Mc/s.

Although the new Central Laboratories in Baden possess a well-equipped metallographic department with expert staff, it appeared desirable for simple

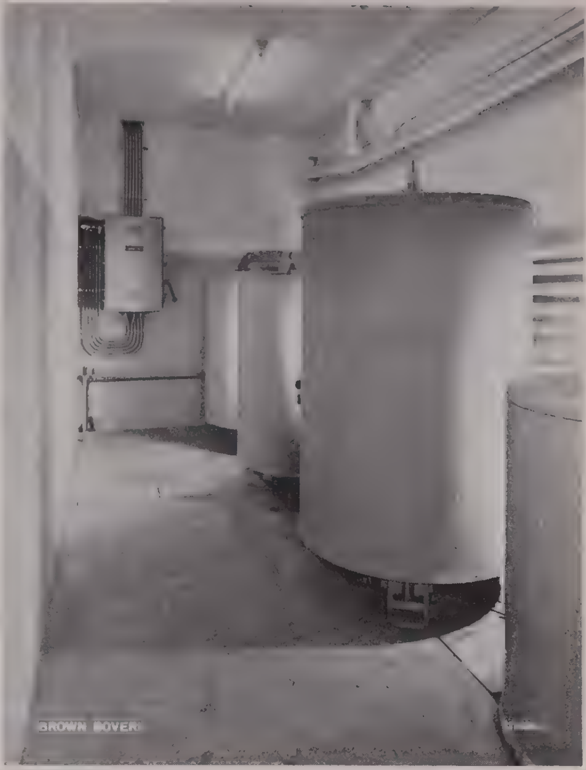


Fig. 154. – Converter room in the laboratory for m.f. and r.f. induction heating

From left to right: m.f. converters 120 kW, 2 kc/s; 100 kW, 4 kc/s; 200 kW, 1 kc/s; 50 kW, 10 kc/s.

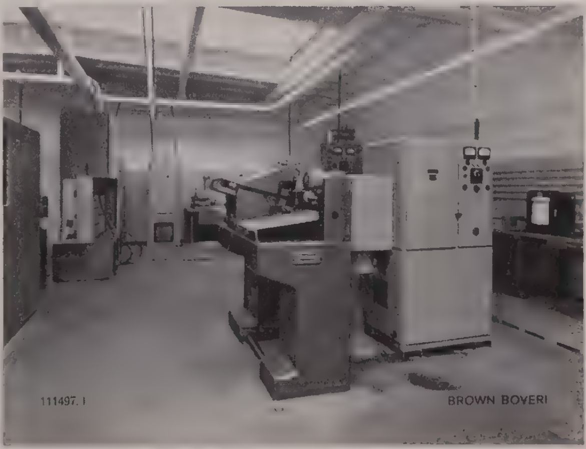


Fig. 155. – Part of the new laboratory for induction heating

On the extreme left is the oscillator cabinet of a 100-kW r.f. generator. In the foreground is a shaft-hardening machine with a 10-kW r.f. generator and, behind it, two generators with rated outputs of 25 kW.

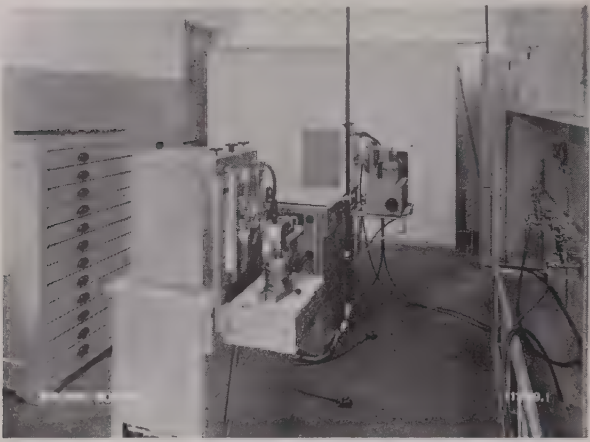


Fig. 156. – Part of the new laboratory for induction heating

with two 4-kW r.f. generators. Fitted to the bench in the foreground is a universal clamp for holding workpieces in any desired position.

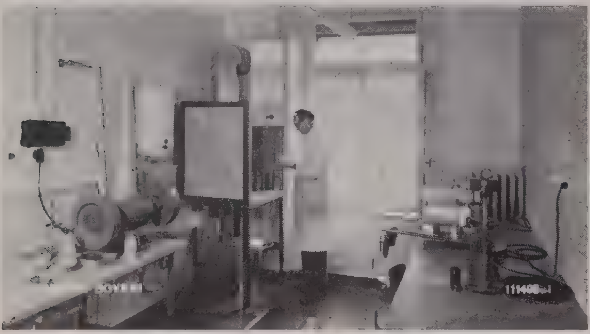


Fig. 157. – Room for grinding, polishing and etching

equipped with a heatable press for embedding metal specimens, a resistance oven controlled by thermostat for temperatures up to 1100 °C, a grinding and buffing wheel for polishing metal specimens and a fume-cupboard for working with chemicals.

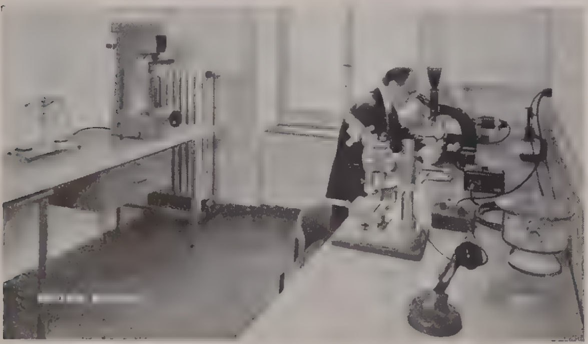


Fig. 158. – Room for metallographic investigations

On the table in the foreground is a portable hardness tester, an apparatus for performing Vickers' hardness tests, and a metal microscope. On the bench at the rear is a universal hardness tester for loads of 62–150 kg, calibrated direct in Brinell, Rockwell and Vickers.

investigations to be undertaken on the spot in the induction laboratory. Thus the main laboratory is augmented by a room for grinding, polishing and etching metal specimens (Fig. 157), with another room (Fig. 158) in which the metallographic investigations are carried out.

2. Heat Treatment

Medium-frequency heating

In the new permanent-way superstructure workshops of the Swiss Federal Railways at Hägendorf near Olten a novel induction unit for the heat treatment of parts of railway points before and after welding has been in service for just over a year. This unit operates at a medium frequency of 1 kc/s and has a rated output of 40 kW. Allowing a heating period of 6–7 min for a length of 20 cm, e.g. for the tongues of points, and a temperature of 650 °C, the entire cross-section can be evenly heated. Fig. 159 gives an impression of the heating unit, which is incorporated in the roller conveyor, and the expediently mounted control unit.

Radio-frequency heating

While the application of r.f. energy in the metal-working industries was mainly confined to tempering or surface hardening of steel parts, to begin with, numerous other uses for this form of heating have been developed lately; for instance, hard and soft soldering, sintering, and the processing of semiconductors. This greatly increases the severity of the demands on the r.f. generators. The general development trend can be characterized by the following requirements:

- Facilities for stepless variation of the output of the generator while running,
- Adaptation to inductors with very small effective resistance (high quality factor), as encountered in soldering, where the inductor mostly contains non-ferrous metals which are good electrical conductors,

- The use of industrial electron tubes specially designed for employment in heating generators.

In the majority of the r.f. generators built by Brown Boveri for small outputs, the *power variation* is effected by the system of d.c. voltage control with horizontally controlled thyratrons, developed several years ago. In future, however, this method of control will be adaptable to changes in the elements of the r.f. circuits of the generator. From the wealth of possible methods, two quite well-known methods were selected and have been tried out in practice.

An example of the first solution is the type 100 L 1 r.f. generator with a terminal output of 100 kW (Fig. 160 and 161 show the air-cooled model). The oscillator circuit consists of the bank of water-cooled ceramic capacitors, visible at the bottom of Fig. 162, and the oil-insulated r.f. transformer above them. With this design the power is varied by vertically displacing the primary coil relative to the secondary cylinder by means of a spindle, which can be driven by hand or by a motor. The generator has a working frequency of 580 kc/s and is employed for hardening in the French automobile industry.

The second version of matching control is illustrated in Fig. 163. Here the variable adaptor is designed as an auto-transformer, the individual inductances of which are variably coupled with one another on the principle of a variometer. By rotating the inner part of the coil through 180 ° with a handwheel or motor driving the vertical axis, the coupling factor can be theoretically varied between 0 and a maximum. The main advantage of this method is the rapid, inertialess adjustability of the coupling, permitting major power fluctuations during the process to be corrected without heavy outlay for servo-mechanisms. Fig. 164 shows the standard 12-kW unit modified from push-pull to operation as

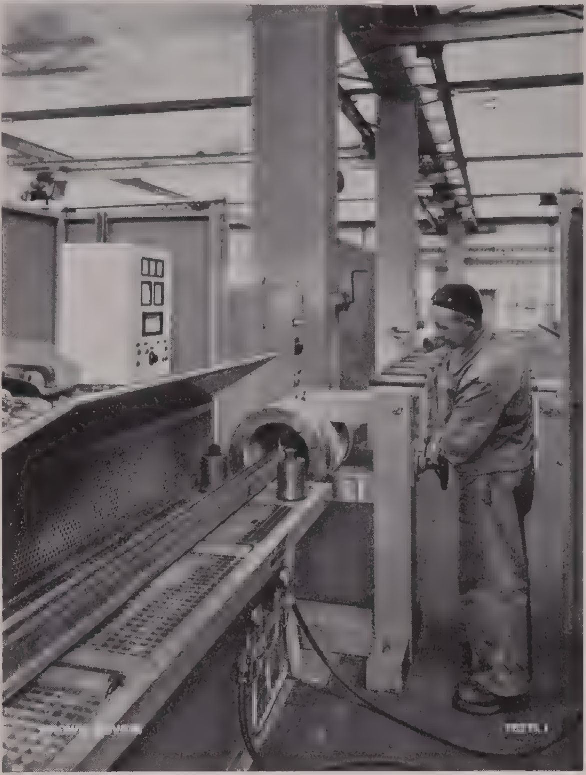


Fig. 159. – Medium-frequency induction heating unit for tempering parts of railway points before and after welding, installed in the Superstructures Workshop of the Swiss Federal Railways at Hägendorf

Input 40 kW, 1000 c/s Temperature 650 °C

When a 200 mm length of point tongue is raised to the above temperature for 6–7 min, the entire cross-section is uniformly heated.

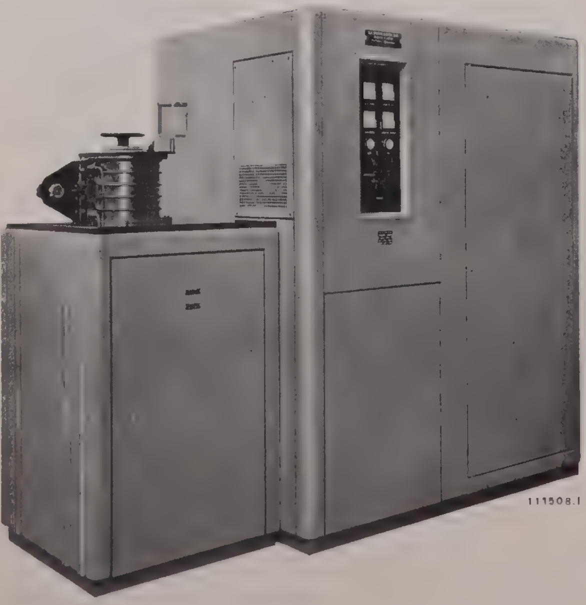


Fig. 160. – Inductive 100-kW r.f. generator with air cooling

On the left is the variable adaptor on the capacitor cabinet, on the right the oscillator cabinet with the control panel.

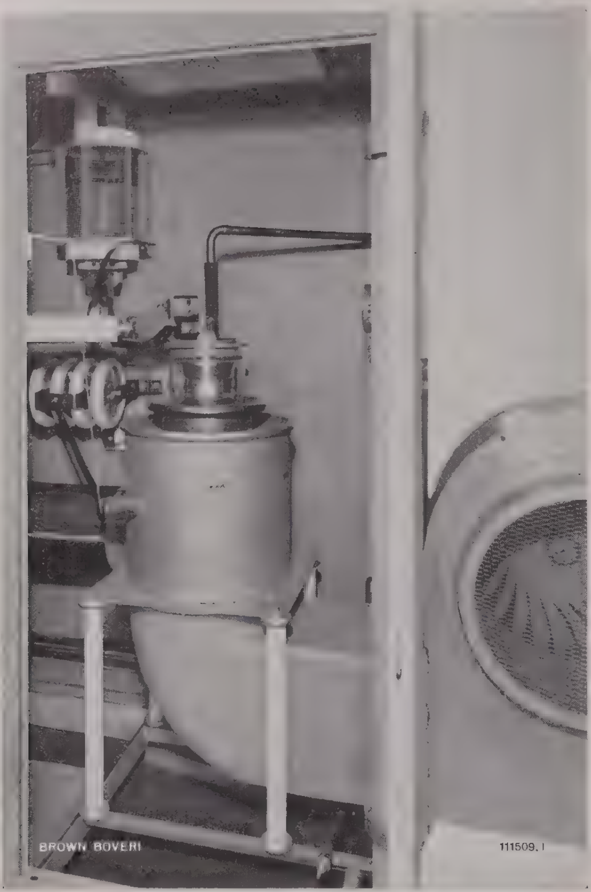


Fig. 161. – Air-cooled 100-kW r.f. generator

View inside the cabinet containing the tubes. In the foreground is the air cooler of the triode type BTL 50–1 with an insulating air duct; right: the built-on fan.

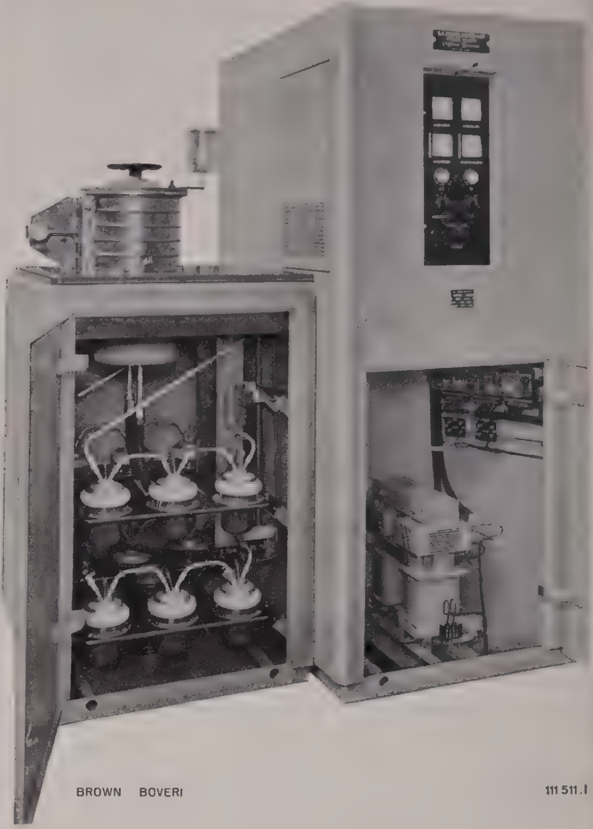


Fig. 162. – Inductive 100-kW r.f. generator

View inside the adaptor. At the bottom is the capacitor bank of series-parallel water-cooled ceramic capacitors. Above it, the r.f. transformer with connection for the inductor. Bottom right is the heating transformer with mounting for the oscillator tubes.

a Hartley oscillator with two parallel tubes type FTL 8–1, with the built-on variable adaptor.

The first four generators of this type were delivered early in 1960 to the Japanese firm Fujikoshi Kozai. There they are used for pre-heating blanks of high-speed steel 8–10 mm in diameter up to about 1100 °C following which they are converted into twist-drills in a special rolling machine supplied by Rhode & Dörrenberg of Düsseldorf, Germany. The good results obtained with this installation led to another order for four generators of the same type, received from the Kobe Steelworks, Japan.

The *matching problem,* as will be well known, is particularly difficult when the generator has to be loaded with inductors having a high quality factor (low effective resistance), such as may be experienced with poor coupling to the workpiece or during soldering with non-ferrous materials. In such cases a compromise must be struck between the L/C ratio (installed reactive power) and the magnitude of acceptable losses. Although the availability of relatively cheap water-cooled ceramic capacitors with high capacitance greatly simplifies the matching problem, there are nevertheless cases where modification of the circuit are inevitable. A measure of this kind is the well-known method of tuning, partially or completely to resonance, of the secondary circuit of an adaptor equipped with a r.f. transformer. For instance, a generator supplied to CIBA of Basle, with a rating of 12 kW, an inductor quality of

$Q = 80$ and relatively low losses of about 3 kW in the circuit, can still produce an output of 10 kW at the terminals.

The stipulation regarding the use of modern *tubes*, some of which were designed specifically for use in industrial generators, was met by the following allocation:

Generator type	Tube type
4 L	FTL 3–1
10 L/12 L	FTL 8–1
25 L	BTL 6–1
50 L/W*	BTL/BTW 25–1
100 L/W*	BTL/BTW 50–1

* The r.f. generators with terminal outputs of 50 and 100 kW can be supplied with either air (L) or water (W) cooling.

In order to exploit the many and varied opportunities for r.f. induction heating for batch production in the metal-working industries as rationally as possible, it has become essential for *charging machines* of all kinds to be developed and made available. In an endeavour to meet the ever-increasing demand for such machines, the Company have extended their range by a number of new types. Fig. 165 shows an automatic shaft-hardening machine primarily intended for the inductive hardening with automatic feed of large batches of cylindrical shafts and pins without any collar, with diameters ranging from 7 to 35 mm and 80 to 500 mm in length. The machine is equipped with an automatic programming mechanism which enables the parts to be hardened for their full length or only in specific zones, with variable preset rotation and feed speeds. The parts to be hardened are stacked in a magazine and transferred automatically from there to the feed mechanism. This is a typical special-purpose machine. In contrast, Fig. 166–169 depict universal machines with which all kinds of induction heating problems can be solved, and the initial cost of which is well within the reach of small and medium plants.

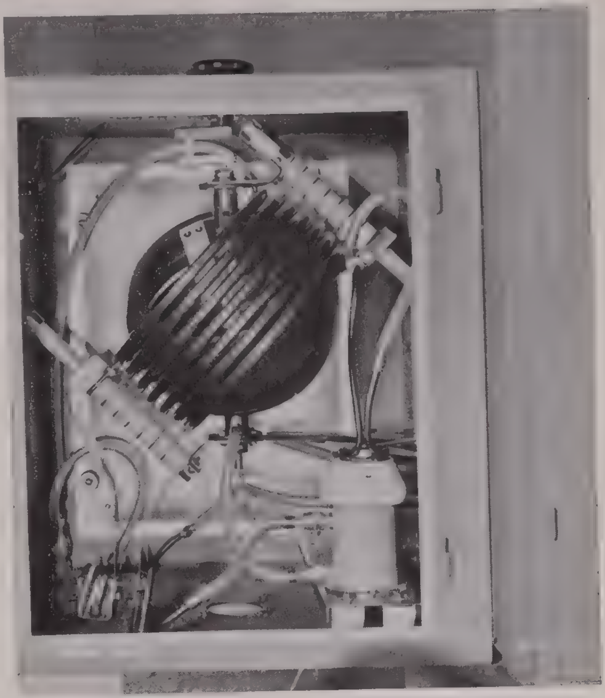


Fig. 163. – Inductive r.f. generator with adaptor

The control adaptor is designed electrically as an auto-transformer, mechanically as a variometer.

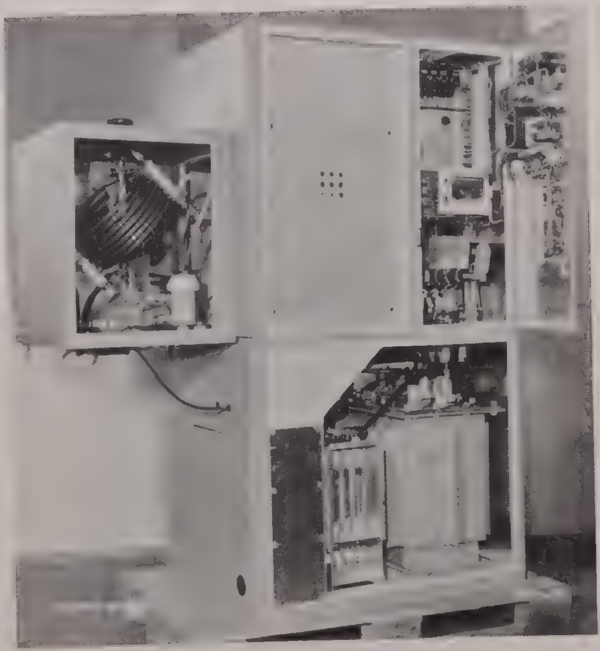


Fig. 164. – Inductive r.f. generator with two tubes type FTL 8–1 acting as Hartley oscillator, and variable adaptor

Top left in the open cabinet is the adaptor, bottom right the anode transformer and top right the control gear.

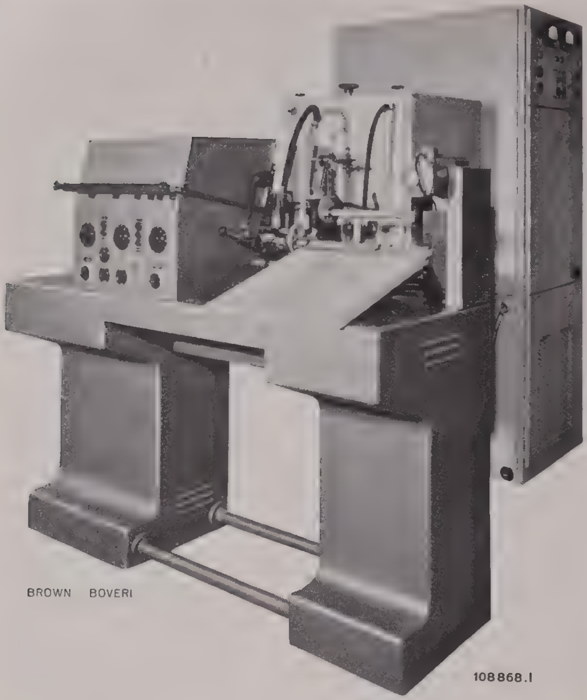


Fig. 165. – Automatic shaft-hardening machine

On the left is the magazine with control panel for the automatic programme mechanism; beside it the clamping and feed elements for the shaft being hardened, complete with inductor and douche.

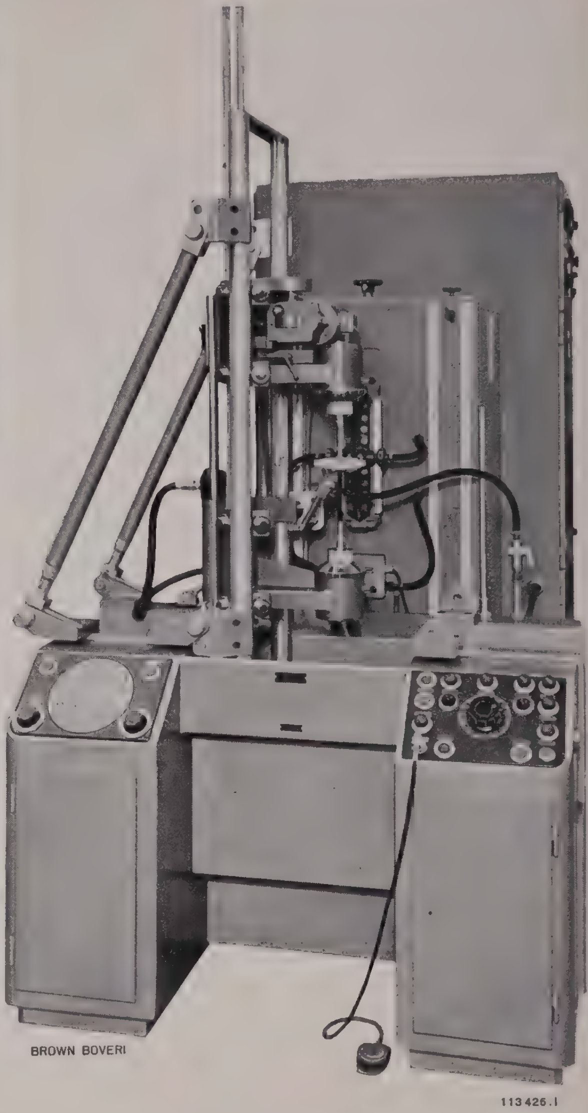


Fig. 167. – As Fig. 166, but arranged for vertical feed

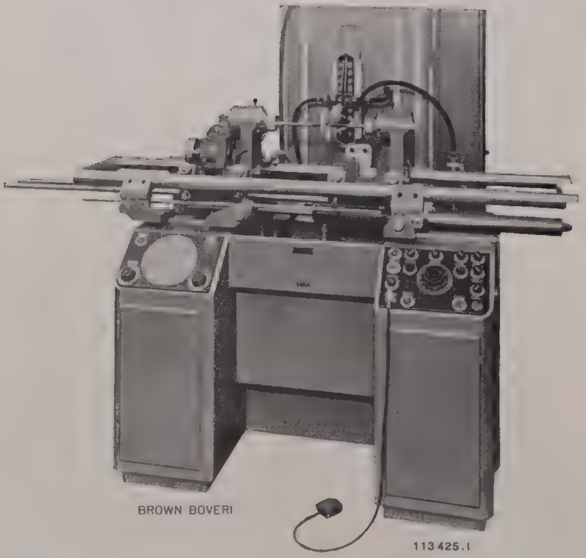


Fig. 166. – Universal charging machine

Arranged for hardening shafts with horizontal feed. On the desk on the left is the selector for the automatic programme control.

These machines are designed on the building-block principle, a constant basic chassis containing all the elements required for the automatic programme control being augmented by a variety of interchangeable supplementary elements. For example, Fig. 166 and 167 show a type with a shaft-hardening device which can be operated in the horizontal or vertical position, and Fig. 168 a supplementary device for hardening saw-blades and band-saws.

For work with the smallest r.f. generator rated 4 kW, the range of machines has been extended by addition of the basic unit with appropriate supplements, of which Fig. 169 shows the semi-automatic turn-table soldering machine.

3. *Soldering and Brazing*

Of the large number of r.f. generators supplied for this purpose, one installation for soldering large pole-coils is particularly interesting. It consists of two halves. In the first, open single turns of four straight copper bars are made with three mitred soldered joints. For this work two r.f. generators rated 25 kW are employed, connected by feeder lines and r.f. changeover switches to any of three adaptors. Two of these adaptors, which contain the oscillator circuit and the r.f. transformer, are mobile complete with the soldering table and inductors, and connected by sliding contacts to the feeder lines. In the second half, fed in a similar manner from a third generator, the finished individual turns are soldered together to form complete coils.

4. *Heating for Hot-Pressing, Forging and Stamping*

Medium-frequency billet heating

About the middle of 1960 an electrically heated installation for preheating forging blanks was taken into service at the Ganterschwil, Switzerland, works of the firm of H. Schwarz. This is employed for feeding a drop-forging press and is designed to handle 100 kg of steel billets per hour with diameters between 18 and 40 mm, raising their temperature to 1200 °C. As Fig. 170 shows, this unit forms a very compact assembly.

Radio-frequency heating for pressing

In addition to the well-known automatic charging machines used for hot-pressing of small parts, a special machine for the hot-pressing of bicycle-tyre valves from cylindrical brass blanks has been devised in collaboration with Ed. Dubied S.A., Couvet, Switzerland. This installation, which is equipped with a r.f. generator rated 10 kW, handles 3000 blanks per hour, 12 mm in diameter and 14 mm

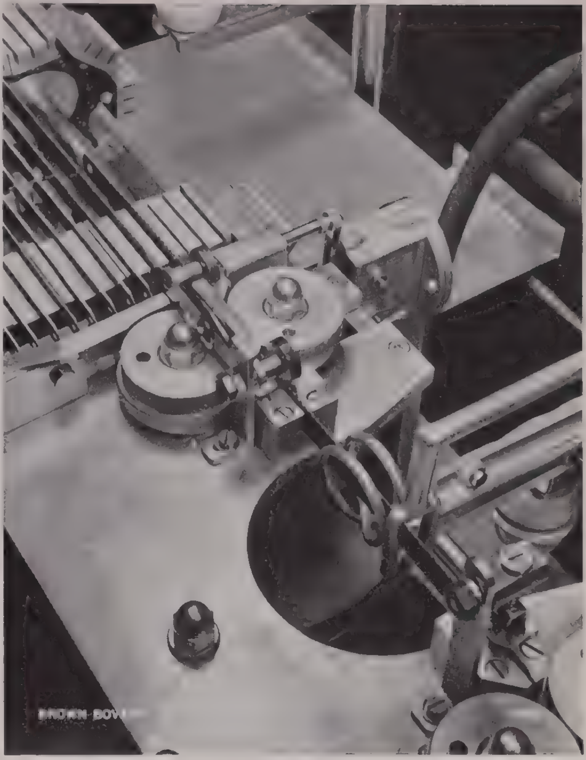


Fig. 168. – Universal charging machine for hardening saw-blades

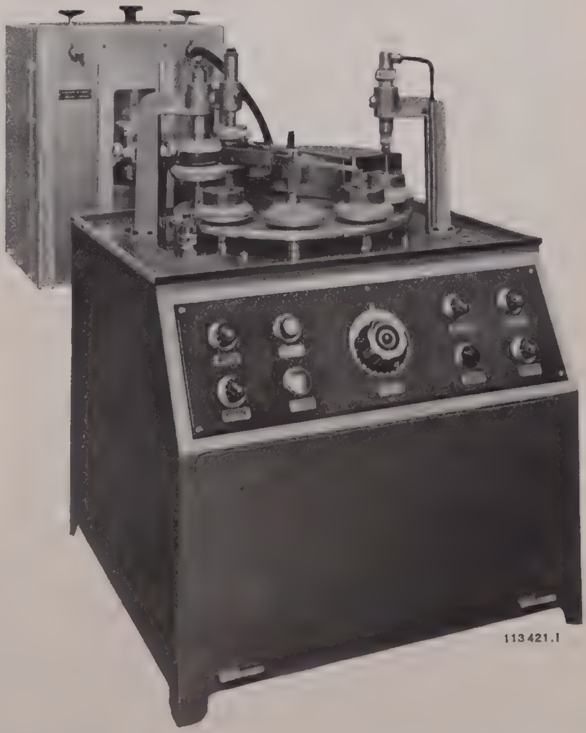


Fig. 169. – Turntable soldering machine arranged for soldering brass floats

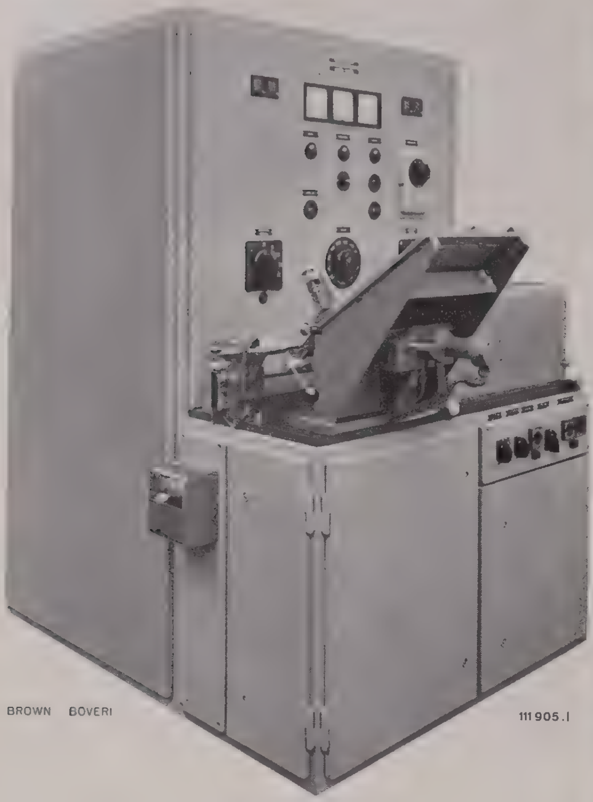


Fig. 170. – Medium-frequency induction unit for heating drop-forging blanks, installed at H. Schwarz, Ganterschwil, Switzerland

Input rating	40 kW
Output capacity	100 kg/h
Diameter of blanks	18–40 mm
Temperature	1200 °C

long, and has been operating very satisfactorily ever since it was commissioned in the autumn of 1959. Fig. 171 depicts the automatic machine opened.

D. Radio-Frequency Dielectric Heating

Among the wide variety of tasks which r.f. generators have to perform, one deserving particular stress is the use for *glueing book-backs*, a process which Brown Boveri have developed in collaboration with the Maschinenfabrik Martini AG., Frauenfeld, Switzerland. Compared with former methods, this new process greatly increases the productive capacity and can be used for book-backs of all conventional sizes, including, for example, telephone directories. With a r.f. generator having a terminal output of 10 kW it is possible to attain a productive rate of about 30 m^2 of glued book-backs per hour. Fig. 172 shows the electrode system of the working capacitor, over which

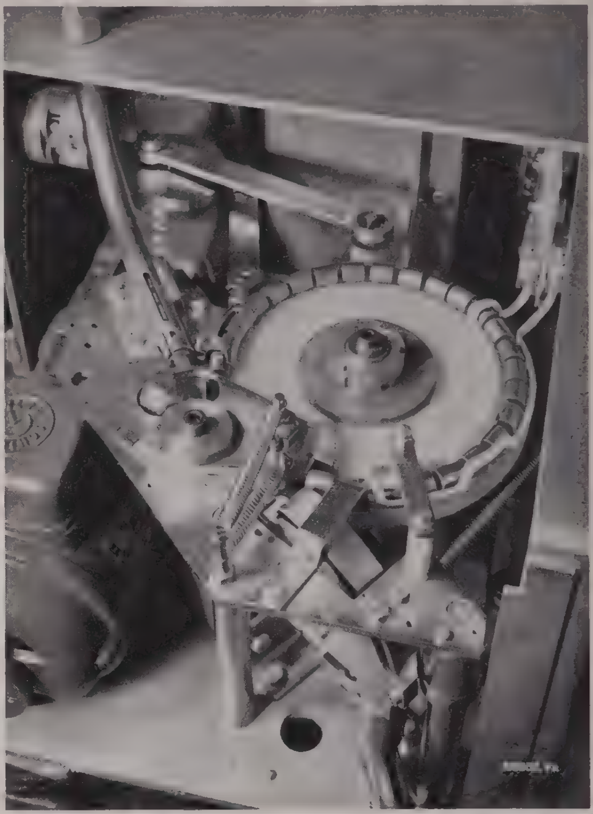


Fig. 171. – Charging machine for r.f. hot-pressing of bicycle-tyre valves

The blanks are conveyed from a magazine, through the tube visible top left, by means of a lever mechanism on to a quartz slab with an annular slot. This is advanced by one notch each time by means of a ratchet system until the blanks enter the heating zone formed by a hairpin inductor. Having been heated to the requisite temperature, the blank is then ejected and conveyed to the press via the channel visible bottom right.

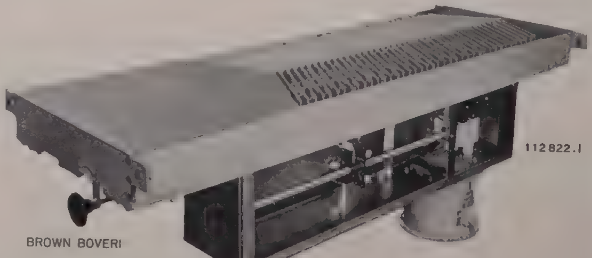


Fig. 172. – Working capacitor for glueing the backs of books

the glued book-backs slide with the aid of a transporting mechanism. Up to the present, seven installations of this size and five with an output of 4 kW have been supplied to noted publishing houses at home and abroad.

E. Electric Welding

1. Arc Welding

During the last ten years tremendous progress has been made by welding techniques, but even today this evolution is by no means at an end. More efficient methods of welding are continually being discovered, requiring new equipment. The sources of welding current have also passed through a phase of development. They have had to be adapted to the new methods; moreover, for ordinary manual welding, new devices have come on to the scene, above all the welding rectifiers. In spite of this, the welding converter continues to attract growing attention.

The existing range of *welding converters*, for instance, has now been extended by the new type GSM 1200 (Fig. 173). This machine is expressly designed for operation with automatic welders and its output is variable between 250 and 1200 A. Its no-load voltage has been made sufficiently high to enable it to cope with all welding tasks within this range, due regard being paid to the arc voltages required. Its weight is only about 760 kg.

In the last review of progress mention was made of the facilities for changing the converter type GSMr 750u from a drooping characteristic for manual welding to a flat or slightly rising characteristic for gas-shielded welding; if requested, the smaller models in this range can now be adapted to provide this facility, i.e. GSMr 500 (60–500 A) and GSMr 375 (45–375 A).

Fig. 174 shows a new *welding rectifier*; its output is infinitely variable between 25 and 270 A. At maximum current it can be employed for continuous manual welding (60% duty cycle). Two current ranges are provided, namely 25–100 A and 80–270 A, in the lower of which all conventional electrodes up

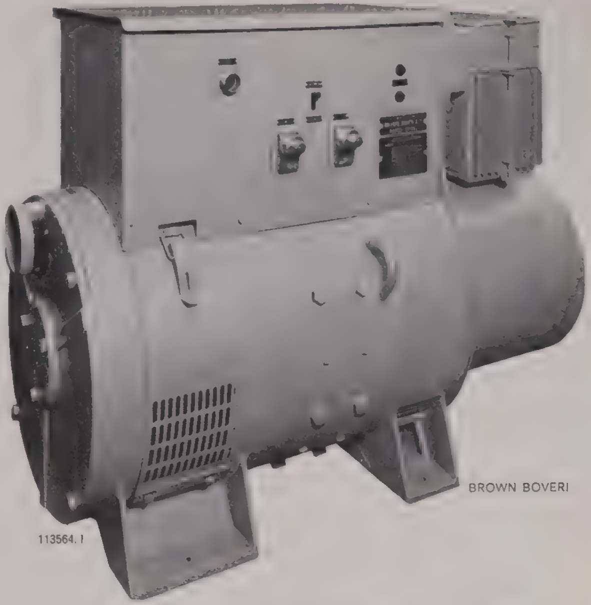


Fig. 173. – Welding converter type GSM 1200

This machine is specially designed for feeding automatic arc welders in continuous service with currents between 250 and 1200 A, and is provided with the appropriate arc voltages. It is started with the built-on star-delta starter with contacts in oil, the welding current being interrupted, not with an expensive main contactor breaking the load current, but simply by interrupting the excitation.

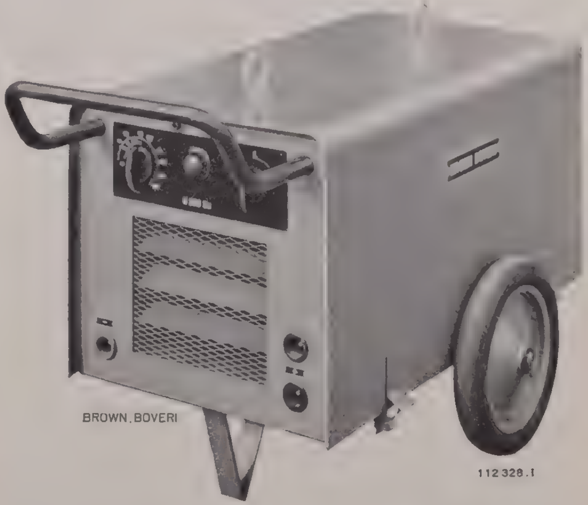


Fig. 174. – Welding rectifier type G 270

for connection to three-phase mains, with built-in main switch and indicator lamp.

By adopting a completely new control principle it was possible to reduce the weight and dimensions to a minimum, thereby enhancing the unit's mobility. The rectifier cells are quite able to withstand a short circuit with the maximum current setting; the unit is also protected against failure of the ventilation. Control is stepless at 25 V between 25 and 100 A, and at 25–30 V from 80 to 270 A at 60% duty cycle (corresponding to the duty cycle for manual welding). If specially requested, remote control can be provided.

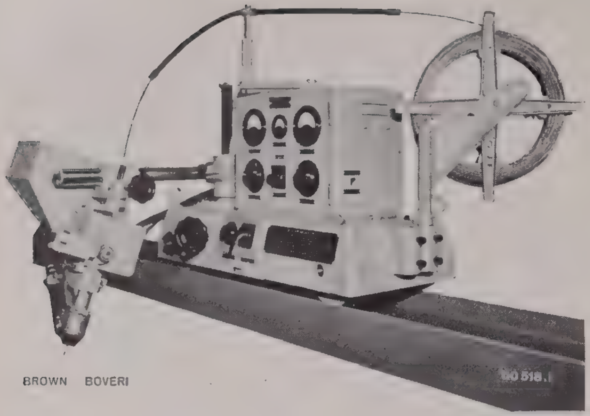


Fig. 175. – Universal automatic arc welder type E 1200 with automatic regulation of the arc voltage

Can be used for the following welding processes: submerged arc, single and twin wire – mesh-coated electrode – bare wire shielded by CO_2 – flux-cored electrode – Brown Boveri "Visarc" process with magnetic flux.

Diameters of wires: 1·2 to 6 mm at currents up to 1200 A and with carriage speeds of 0·1–2·5 m/min. The welding nozzle can be easily adapted to the various tasks and accurately adjusted in service. For special applications the welder can be quickly dismantled into its component parts.

to 2·5 mm diameter can be employed, while in the upper range it is possible to weld with all electrodes up to 5 mm in diameter. Its dimensions and weight (appr. 170 kg) are quite small. This was made possible by the adoption of a new control principle. The rectifier elements are so designed that they can withstand a persistent short circuit at the maximum current setting. Moreover, in the event of the fan failing, all thermally stressed parts are protected by a relay responding to the air-flow. An indicator lamp in the middle of the control panel shows whether the unit is switched on or not. Remote control can be provided if expressly stipulated.

New designs have also been brought out in the field of automatic welders. In addition to a small, very reasonably priced single-purpose welder for submerged-arc welding (type EV 1000, capable of welding at 1000 A on both a.c. and d.c.), attention may be drawn to the new universal type E 1200 (Fig. 175). While retaining many of its constructional features, the latter supersedes the type U 1200 which has rendered good service for many years, and has been produced in hundreds. As a result of well-planned design, it has proved possible to reduce the total weight by about 30 %, which should be of great value in practice. The working range of the E 1200, from 200 to 1200 A, allows this welder to be used with electrodes from 2·5 to 6 mm in diameter. Its versatility from the welding aspect is eloquently expressed in the list of welding processes for which it can be used:

- Submerged-arc welding with single or twin electrode wire,
- Welding with mesh-coated electrodes,
- Gas-shielded welding under CO_2 or argon (MIG process),
- Shielded-arc welding with flux-cored electrodes under CO_2,
- Welding with magnetic flux, using the Brown Boveri "Visarc" process.

In by far the majority of cases the automatic welder is mounted on rails (as in Fig. 175). However, dispensing with the undercarriage, it can be employed as a stationary unit and incorporated in a welding fixture, for instance, or attached to a manipulator (or welding mast and boom).

Depending on the conditions specified, stationary units can be equipped with two welding heads. In this case the welding programme can be extended to include such special processes as tandem welding (i.e. with the heads in tandem) or series-arc welding (with the two heads electrically in series).

For *shielded-arc welding* under *argon*, which was primarily visualized as a manual process (TIG welding), additional applications have presented themselves as time has passed, due to the incorporation of the torch in mechanical fixtures, so that it could be included in the working procedure in such a manner that the term automatic welding equipment can be justifiably applied.

Fig. 176 illustrates an installation of this kind, employing a Brown Boveri gas-shielded welder type WS 300, with which small containers for the refrigerator industry are produced. A single starting

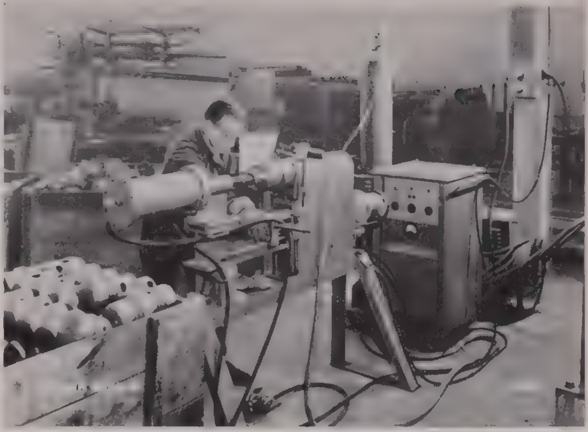


Fig. 176. – The use of TIG welding in the manufacture of expansion vessels for refrigerators from deep-drawn sheet-steel

As a result of the expedient preparation of the edges, a perfectly vacuum-tight seam is obtained, free from inclusions. The workpiece is clamped pneumatically. Following a single switching operation, the programme continues automatically.

command sets in motion the entire sequence of operations, all precisely co-ordinated with one another, namely the rotary movement, control of the gas flow, welding current, current reduction.

When automation is expediently performed, it is possible to make the welding process so rational that TIG welding, which is not particularly cheap in itself, can be economically used for welding steel. A further means of increasing the working capacity is to utilize several welding torches at once on a single workpiece.

2. Resistance Welding

Owing to its extremely good economy, *projection welding* continues to make its predicted progress in the sheet-metal industries, i.e. in the manufacture of equipment and steel furniture. The Brown Boveri spot welders of the C series can be equipped with welding tables, enabling them to be used for small

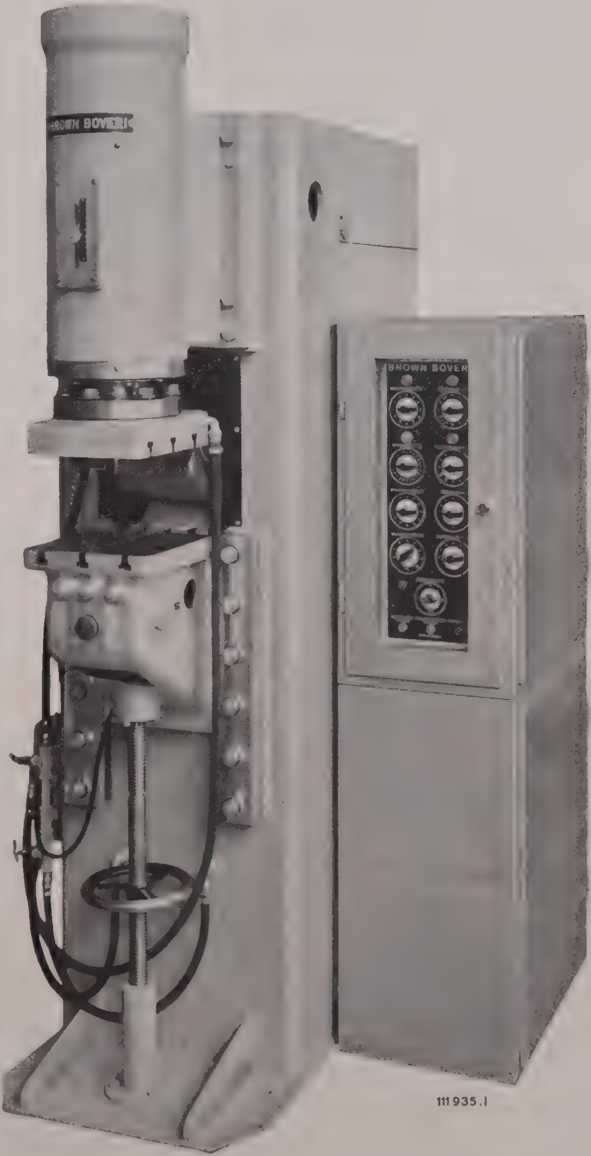


Fig. 177. – Projection welding machine type BU 15 with electronic control type PUNZIb

Depending on the number of projections to be welded in one action, the projection welding machine has to produce high electrode forces and carry a heavy current. For this reason the *machine* has very short arms, so that it is very rigid and can withstand very heavy welding currents.

Max. welding current	50– 60 kA
Electrode force	300–1500 kg
Thicknesses welded	0·5– 3 mm
Number of projections	12– 5

The *control unit* contains the timers controlling the squeeze time, weld time, hold time, and off time. The welding current can be varied electronically between 20 and 100%, and can be fed to the weld all at once or during a series of pulses, if desired with slope control. The unit can also be used for controlling seam or combined seam and spot welding machines.

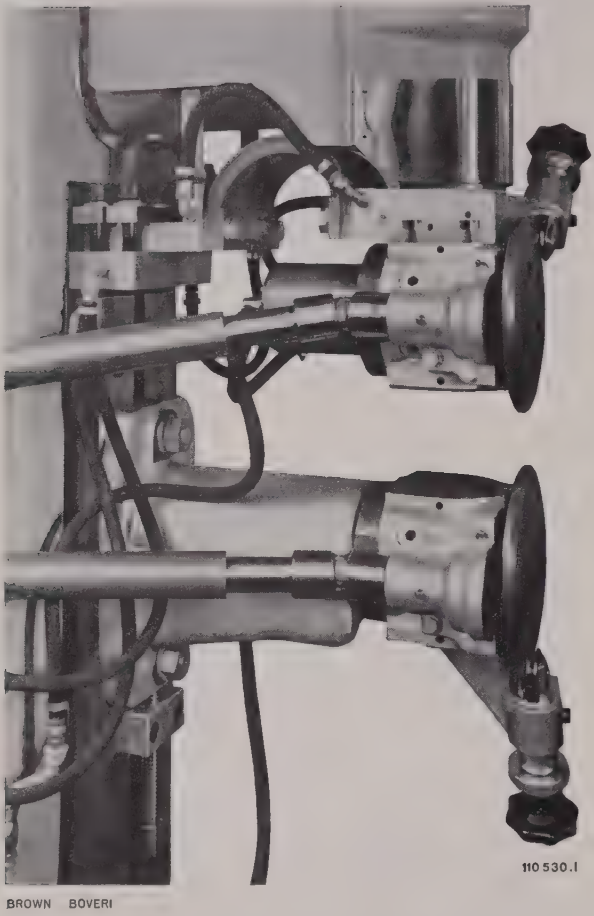


Fig. 178. – Seam welding machine equipped with brush-roller heads in needle bearings

These heads can carry a much heavier current and have a longer life than the former design with plain bearings.

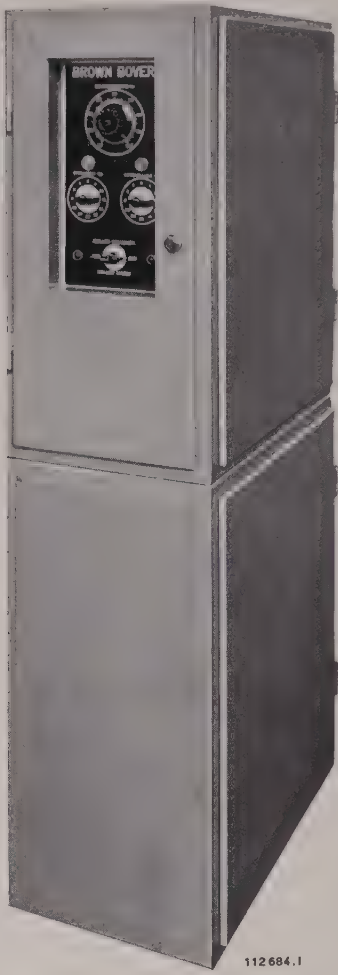


Fig. 179. – Electronic seam-welding control type INZ

This unit can be employed for controlling seam welding machines. The two timers for the periods in which the current is flowing and not flowing switch the welding current, variable electronically between 20 and 100% with the interruptions usual for seam welding. For special applications it is possible to weld with sustained current. The drop in current occurring when welding longitudinal seams on sheet-steel can be compensated for, if necessary.

projection welding tasks. Already considerable success has been achieved with the projection welding presses designed for multiple-spot welding and capable of exerting an electrode force of 3 t. The projection welding machine recently brought out, with an electrode force of 1·5 t (Fig. 177), has closed the gap between the small and the large machines.

An interesting addition to the accessories for seam welding is the newly designed brush-roller head (Fig. 178). With the former, generally well-known form of roller head a plain bearing of non-ferrous metal transferred the welding current from the roller journal to the electrode wheel. The severe strain imposed on the bearing shells by the passage of the current and the bearing friction imposed a restriction on the load capacity of the roller heads. A new approach was adopted with the latest design of roller heads. The mechanical support of the roller journal is taken over by a pair of electrically insulated needle bearings, the current being transferred to the journal by metal brushes. This increases the permissible loading and prolongs the life.

The efforts directed towards cheapening existing *control systems*, as well as improving them technically, has resulted in some new systems being devised. The standard model for normal *spot welding* contains four synchronous-precision timers for controlling the "squeeze time", "weld time", "hold time" and "off time", the lengths of which vary between 0·04–2 s, 0·02–2 s, 0·02–10 s and 0·04–1 s, respectively. The welding current can be varied between 20 and 100 % by shifting the firing point of the control tubes. To obviate alloying by the electrodes when welding aluminium, the control system is also equipped with slope control, with current rise times of 0·05, 0·1, 0·2 and 0·4 s.

The chassis described can be supplemented by a timer for the current interval, permitting the execution of *seam and pulsation welding* (see Fig. 177). The number of pulses, adjustable within the weld and off times, can be varied between 1 and 10. With slope control it is possible for the current to rise to its ultimate value within the duration of one pulse, or it can be spread over a number of pulses. An energy regulator can be added to both units, to ensure that uniform spots are obtained, regardless of the state of the surface of the metal.

The *single-purpose seam-welding control* (Fig. 179) only contains two timers, one for the period during which the current flows, and one for time it is not flowing, with the times 0 to 0·28 s. Control of the welding current also permits variation between 20 and 100 %, by shifting the firing point. In addition to the normal method of seam welding with interruption of the current, this control system also permits welding with sustained current at high feed rates with very thin material. Also, when welding longitudinal seams, the drop in current caused by sheet steel entering the throat of the machine can be counteracted by a simple supplementary device on the machine.

V. COMPRESSORS, GEARS AND TURBOCHARGERS

A. Compressors

It is estimated that about two-thirds of the compressors and cryogenic expanders put into service during the past two years have been installed in steelworks. In addition to the traditional applications, these machines are being used more and more for the production of oxygen. An ever-increasing need for oxygen is being experienced in the steel industry for shortening the blast process and raising the quality of the steel, as well as for various applications in rolling mills.

The multi-stage *axial compressor*, the first machine of this type being developed by the Company nearly thirty years ago, has now obtained wide recognition in view of the fact that over 400 units have been produced. It maintains a prominent place in the European compressor industry. Due to its large volume capacity, high efficiency and compact construction it covers a wide range of applications and visibly displaces the centrifugal type of compressor which was previously employed with success. Many years service in gas turbine plants have proved the axial compressor to be a robust and dependable machine.

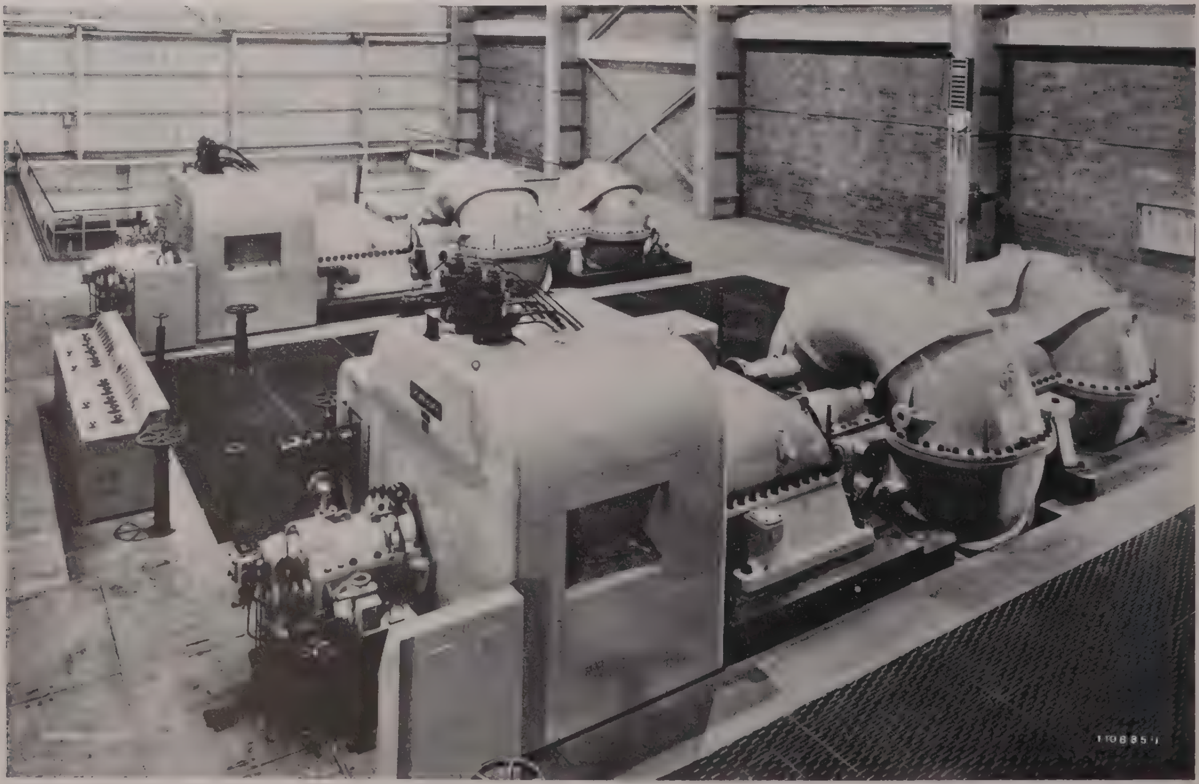


Fig. 180. – Two axial blast-furnace compressors driven by condensing steam turbines for the production of cold blast at the Australian Iron & Steel Co., Port Kembla, Australia

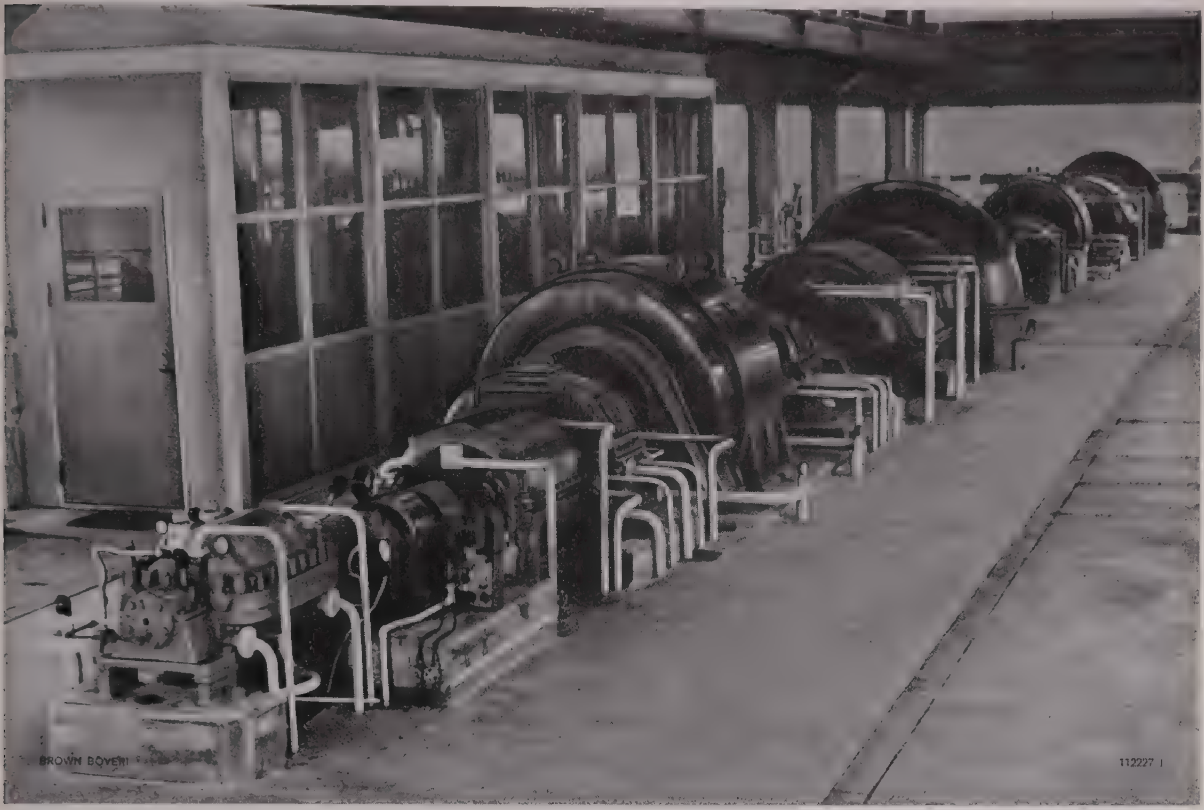


Fig. 181. – Two gas compressors driven by synchronous motors each compressing 98 000 m^3*/h of hydrocarbons from 0·13 to 11·3 bar, supplied to the Japan Synthetic Rubber Corp., Yokkaichi*

In the foreground from left to right: High-pressure cylinder, gear, second i.p. cylinder, gear, motor, gear, first i.p. cylinder, low-pressure cylinder.

Now it is not only finding a place in new plants, but is also being used with equal success to replace old reciprocating and centrifugal-type compressors. The initial doubts of plant engineers regarding the steep pressure-volume characteristic compared with that of the centrifugal machine have practically vanished now that sufficient practical experience has been gained.

Most of the axial compressors delivered to the blast furnaces of steelworks during the last two years are driven by condensing steam turbines. By varying the speed it is possible to achieve optimum economy for the various operating conditions. The largest axial blower sets so far built by the Company for blast furnace blowers were installed in Australia in the spring of 1959, in the record time of eight and seven weeks, respectively. Shortly after, they were taken into service and have been running very satisfactorily since. Each set is designed for an air volume of 212 000 m^3/h, the delivery pressure being 3·46 kg/cm^2 abs and the input requirements 10 500 kW. A condensing steam turbine serves as drive, its live-steam conditions being 43·3 kg/cm^2 and 455 °C (Fig. 180).

In areas where, on the whole, it is less expensive to obtain electrical energy from a large supply network than to generate it locally by small turbosets, constant-speed electric drives are preferred. The same applies to gas turbine sets used to produce electricity and cold blast. In these cases, to obtain the same or better adaptability to all operating conditions, the axial compressor is equipped with a recuperation turbine or, more recently, with manually or automatically controlled variable-pitch stator blades. In the new design of this variable device we were able

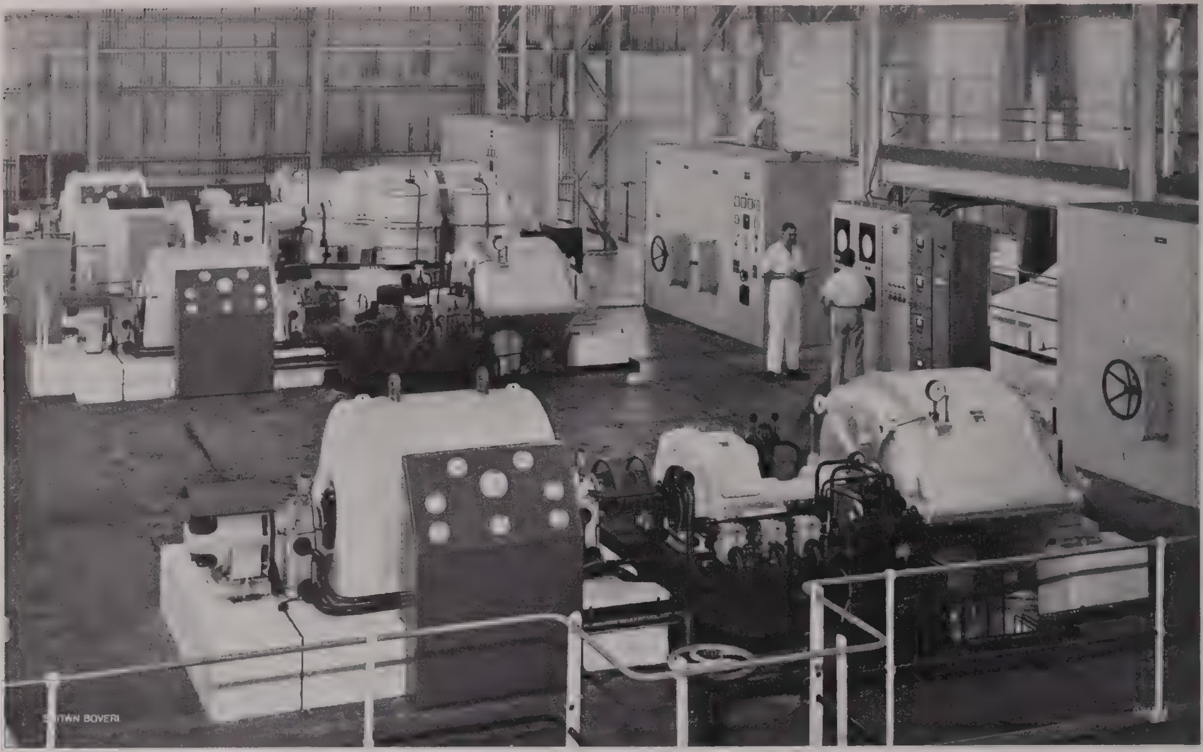


Fig. 182. – Two air compressors for a copper converter at the Mufulira Copper Mines Ltd., Northern Rhodesia

Capacity per compressor 51 000 m³/h, discharge pressure 2·055 kg/cm² abs. By means of a combination of hydraulically operated throttle valves and movable diffusers part loads (down to 25% of total volume) can be handled economically without having to blow-off.

to call on 20 years' experience in the construction of movable diffusers. This solution was also adopted for the l.p. turbine of a twin-shaft gas turbine set and proved very successful when running under much less favourable conditions. Control by adjustable stator blades provides a larger stable working range than that afforded by a steam turbine drive. At the moment four such compressors are being assembled in the Baden works.

The *centrifugal compressor* is still found to be suitable for a large range of applications, a number of these machines having been supplied to steelworks. One of them has adjustable diffusers in every stage. The electrically driven compressors depicted in Fig. 181, which are employed in a chemical plant, deserve particular attention. Each of the two identical sets is used to compress a hydrocarbon mixture from 0·13 bar to 11·3 bar at the rate of 98 000 m³/h. The high pressure ratio of 86·5 and the stipulation that the gas temperature must never exceed 105 °C—because of the risk of polymerization occurring during compression—made it necessary to split each set into several cylinders with intercoolers in series. The arrangement of the 3800-kW synchronous motor in the middle of the set improves its appearance and is technically advantageous. A simple control device within the system of frictionless labyrinth sealing glands stops oxygen from the air penetrating into the compressed gas and also prevents this gas from escaping to the machine room. A further interesting example from the wide range of centrifugal compressors is shown in Fig. 182.

Lively demand continues to persist in the field of *Isotherm compressors* driven by synchronous motors. An interesting example is illustrated in Fig. 183, which shows the "Oxylor" oxygen plant at Richemont (France), officially inaugurated on May 2nd, 1960. This plant was originally designed to produce 365 t

Fig. 183.– The Oxylor oxygen plant in Richemont (Moselle) owned by Société L'Air liquide, Paris

In the foreground one of the three Brown Boveri Isotherm compressors for the compression of a total of 61000 Nm³/h of air. In the background are piston compressors for further compression of the air and supply of the oxygen.

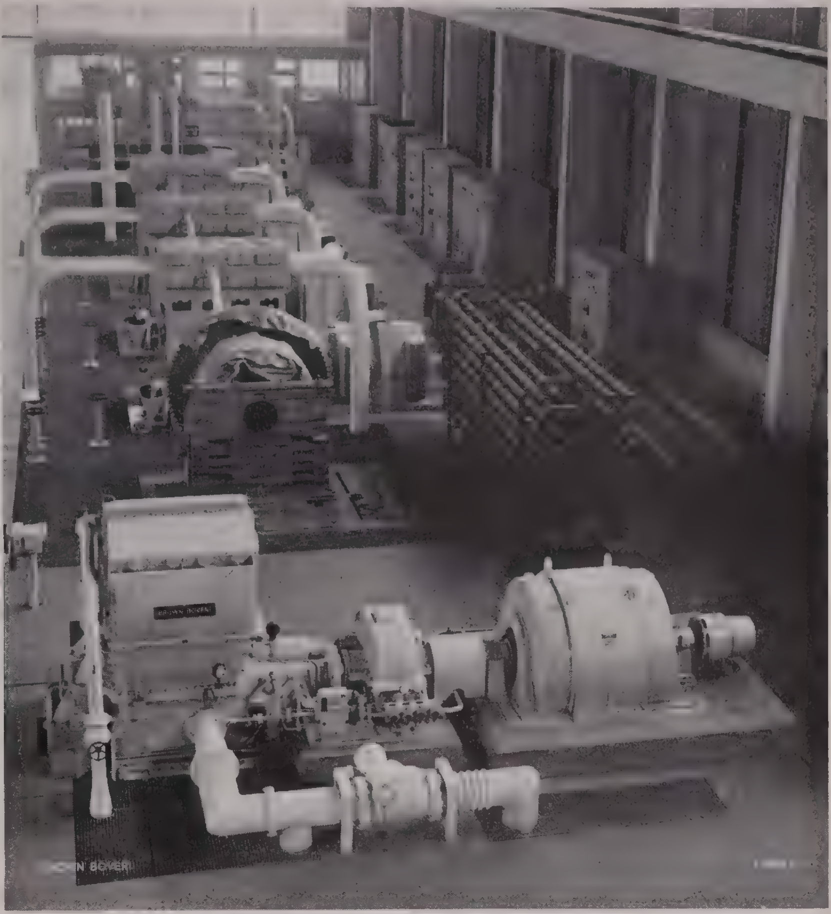
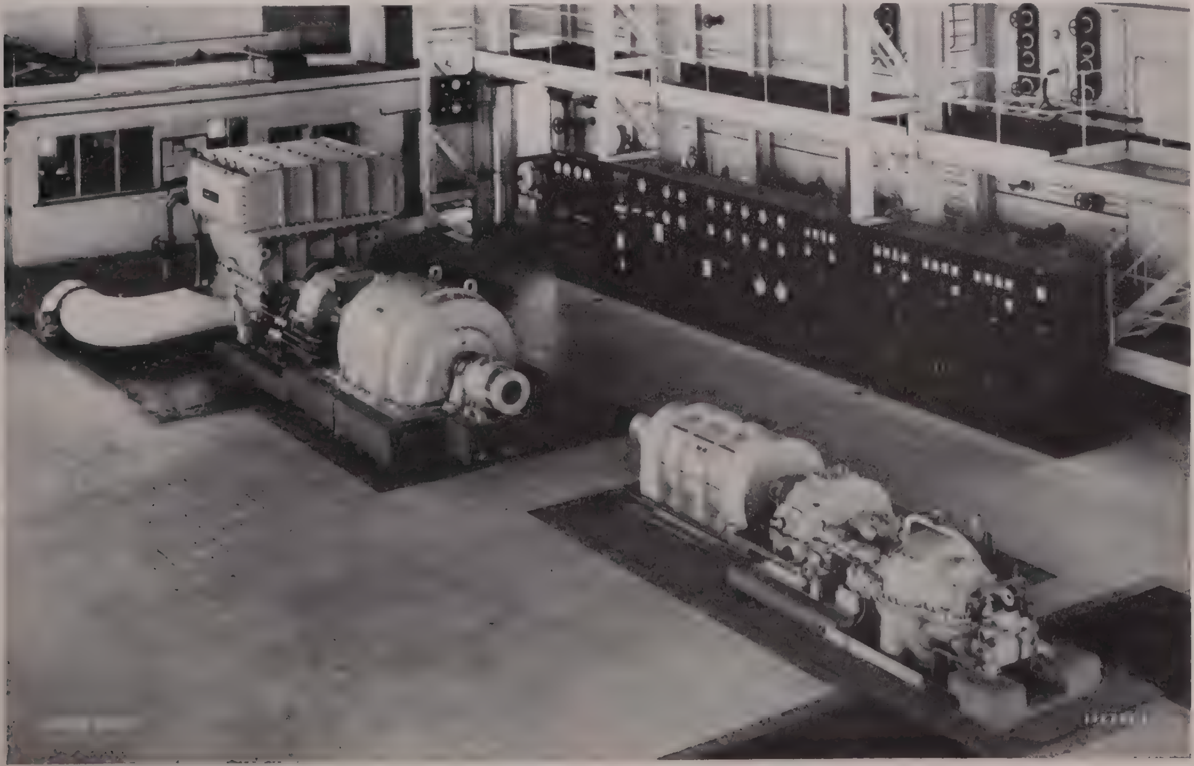


Fig. 184. – Oxygen plant belonging to Stewarts & Lloyds Ltd., Corby, England

In the foreground: right, the oxygen compressor, left, the air compressor; in the background right, the switchgear and supervisory equipment.



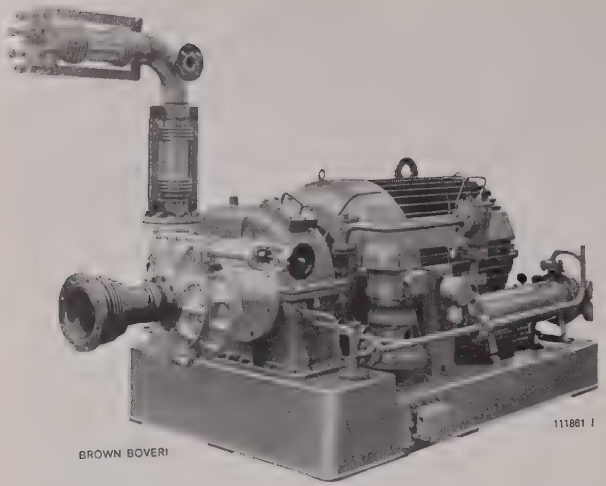


Fig. 185. – One of the two cryogenic expanders of an air separation plant of the Houillères du Bassin de Lorraine, Usine de Carling, St. Avold

built for the expansion of 10 000 Nm³/h from 5·4 bar, 123 °K to 1·37 bar, 93 °K with recovery of 80 kW at the terminals.

of liquid oxygen per day, to be delivered to the neighbouring steelworks. The first compressor was put into service in the autumn of 1958, delivering 11 000 Nm³/h of air at a discharge pressure of 8 kg/cm² (7·84 bar). The second machine, with a capacity of 25 000 Nm³/h at a discharge pressure of 6·2 kg/cm² (6·07 bar), followed nine months later. The third set, which has recently been put into operation, handles the same air volume as No. 2, its final pressure being 6·5 kg/cm² (6·37 bar).

The air and oxygen compressors shown in Fig. 184 are installed at Corby (England). Both were delivered by Brown Boveri, the oxygen compressor having a capacity of 8760 m³/h at a discharge pressure of 4·86 kg/cm² (4·76 bar). Particular attention was devoted to the design of the labyrinth glands, as well as to the safety devices. The set has been in industrial service since the spring of 1960.

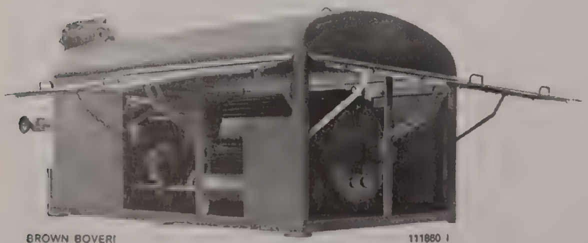


Fig. 186. – The cryogenic expander in Fig. 185 shown enclosed for outdoor installation

In connection with air separation plants it is worth mentioning the *cryogenic expander* with electric brake, of which 29 units have been installed to date. Their simplicity as regards maintenance and the reliability have proved welcome attributes. Fig. 185 shows the compact construction of the set, which can be placed on its foundations as a unit, leaving only the connections for air, cooling water and power to be made. Fig. 186 shows a newly developed alternative design for outdoor installation, capable of withstanding the most unfavourable climatic conditions.

B. Gears

The gears mentioned in the last review of progress, only one of which was in service at the time, have all been commissioned since. They are designed for a maximum power of 35 000 kW and are used with gas-turbine sets. In the meantime further orders have been received for similar gas-turbine gears, also for 3000/3600 rev/min (Fig. 187). Even at these high outputs the axial thrust caused by the meshing of the helical teeth is balanced by a thrust collar on the pinion. This method has proved very successful in thousands of Brown Boveri gears.

Apart for the gears used for gas-turbine sets, many have been taken into service for use with axial and centrifugal compressors driven by electric motors, as well as with electric generators driven by steam turbines. Nitrided teeth are used almost exclusively in gears of this design. More than 90 % of the gears ordered during the past year had hardened teeth.

Operating experience with nitrided gears is so favourable that a larger nitriding furnace has been taken into service, enabling larger gears to be hardened. Previously, the size of the available furnace restricted the size of gears which could be hardened to 2100 mm diameter. With the new furnace commissioned in the summer of 1960 it is possible to nitride gears up to 3300 mm in diameter. The classification societies for marine gears permit hardened

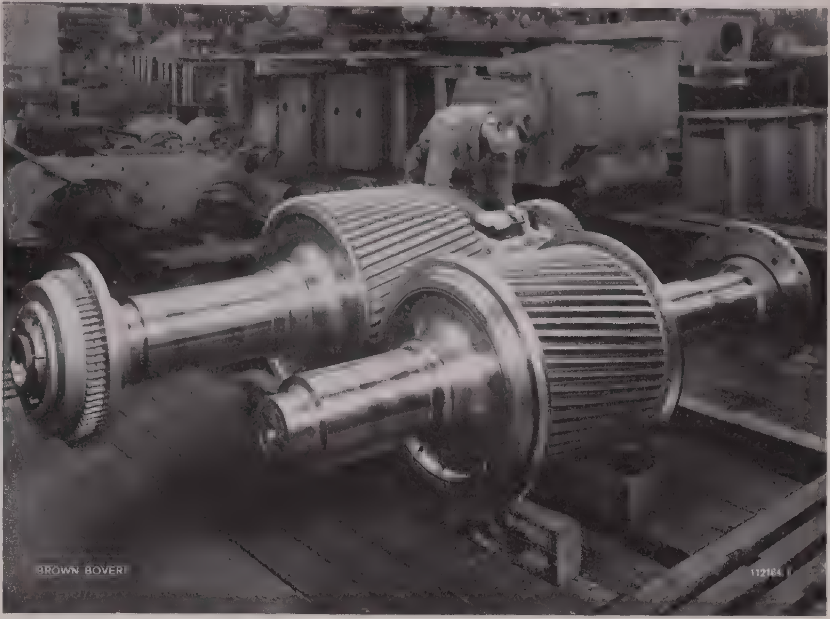


Fig. 187. – Pinion and wheel of a gear for a 15 500 kW gas-turbine set

Speed 3000/3600 rev/min, peripheral speed 122 m/s. The teeth are nitrided. The pinion is fitted with the normal Brown Boveri thrust collars to balance the thrust caused by the single-helical gear design.

teeth to be subjected to much heavier stresses than unhardened teeth. For example, according to the new classification rules of the Germanischer Lloyd, dated April 1959, nitrided unground teeth are allowed to withstand the same stresses as teeth which are case-hardened and ground. Now that the new equipment is available it is possible to design high-power marine gears with nitrided teeth. An interesting gear of this kind is at present being built.

While the large new furnace was being built, equipment was also installed for shaving teeth of wheels up to 4000 mm in diameter. Whereas formerly it was possible to shave gear-wheel teeth up to 600 mm in diameter, the new equipment puts us in a position to improve the surface quality of all gears by application of the shaving method.

C. Turbochargers

As expected, pressure-charging of two-stroke marine diesel engines has experienced quite a boom in the past few years (Fig. 188). In many countries the proportion of turbo-charged engines is already nearly 100%. It is only a question of time until pressure-charging is taken up by all other countries as well.

The demand for large diesel-powered tankers with displacements of 40 000 to 50 000 tons likewise calls for engines with very high outputs. Therefore, the designers of two-stroke diesel engines have undertaken two very important steps during the period under review. Firstly, the degree of charging which, during the first years of two-stroke charging averaged 30%, was increased sharply to 60%. At the same time, engines with cylinder bores of 84 to 90 cm were developed, so that now a single engine can produce up to a maximum of 30 000 bhp. The demand for such machine outputs was not the only reason for the development of large cylinder outputs. For a given engine output and propeller speed, the number of cylinders can be reduced. The economy of two-stroke marine engines can thereby be improved, thus permitting, for example, the change from a sectional to a one-piece crankshaft. In addition, when considering the larger cylinder bores, the cost of upkeep and maintenance are essentially dependent on the number of cylinders. This development opens another field for the application of our largest turbocharger (Fig. 189).

In the last review reference was made to the largest charger, type VTR 750. This type is now the largest in the Brown Boveri range of well-proved turbo-

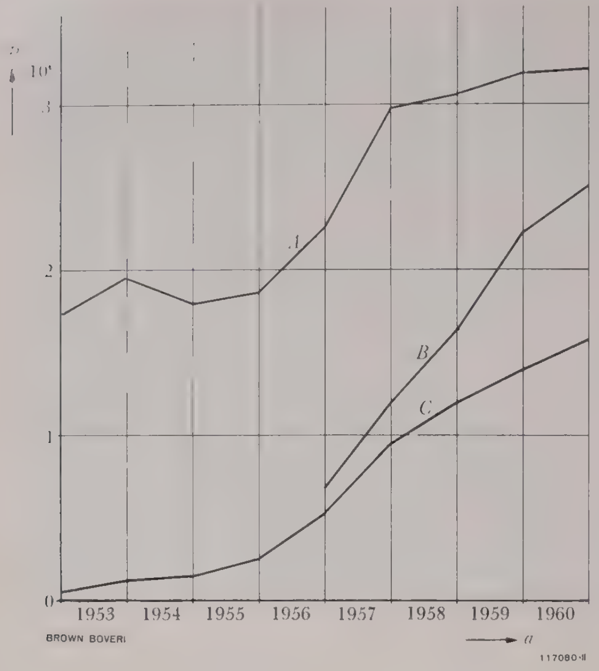


Fig. 188. – Pressure-charging of two-stroke diesel engines

The statistics record only the powers of ships with more than 2000 tons deadweight capacity.

P = Power in millions bhp
a = Year
A = Power of two-stroke marine engines delivered during the year*
B = Power of pressure-charged two-stroke marine engines*
C = Power of two-stroke marines engines supplied with Brown Boveri turbochargers (including licencees)

* From the respective January issues of the periodical "The Motor Ship", London.

chargers (Fig. 190). At present 30 units of this type are already successfully in operation; another 20 are on order.

The introduction of two-stroke engines with larger cylinder bores, as well as increasing the degree of charging did not bring any technical problems worth mentioning from the pressure-charging aspect. A prerequisite for successful continuation of this development is, however, that the engine and turbocharger are well matched to one another. Therefore, we always endeavour to obtain a deep insight into the operation of the engine with the turbocharger. In the last year, a report was published on the exhaust process of pressure-charged two-stroke engines.[1] New calculations augment the examples given at that time (Fig. 191).

Our turbochargers were also selected for charging some newly developed engines (for example

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[1] G. GYSSLER: Investigations into the exhaust process of pressure-charged two-stroke diesel engines. Brown Boveri Rev. 1960, Vol. 47, No. 1/2, p. 73–85

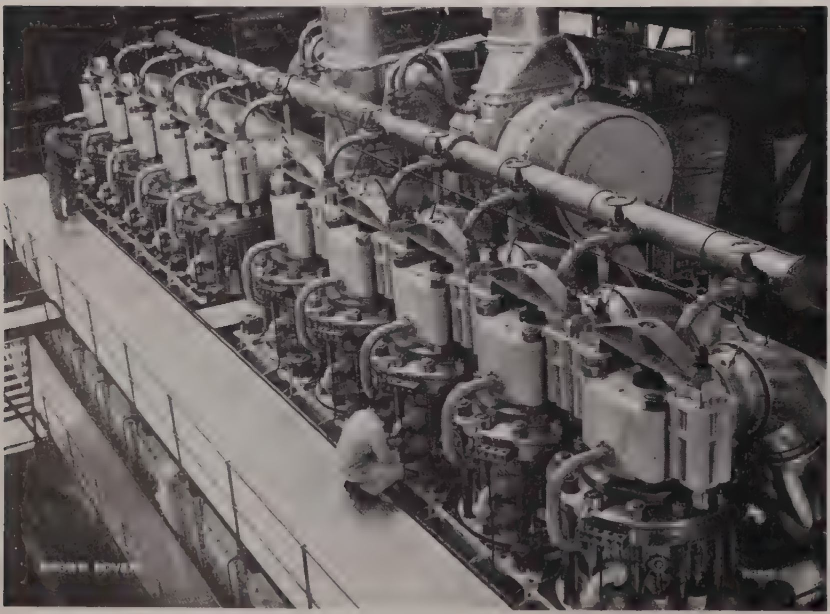

Fig. 189. – View of two Brown Boveri turbochargers type VTR 750 on the Götaverken-engine 850/1700 VGS 10 u

This ten-cylinder engine is the first of the new type with increased cylinder dimensions (850 mm bore, 1700 mm stroke). The engine furnishes a maximum of 18350 hp at 115 rev/min and drives a 40000-ton tanker. At the time of commissioning it was the most powerful two-stroke engine ever built.

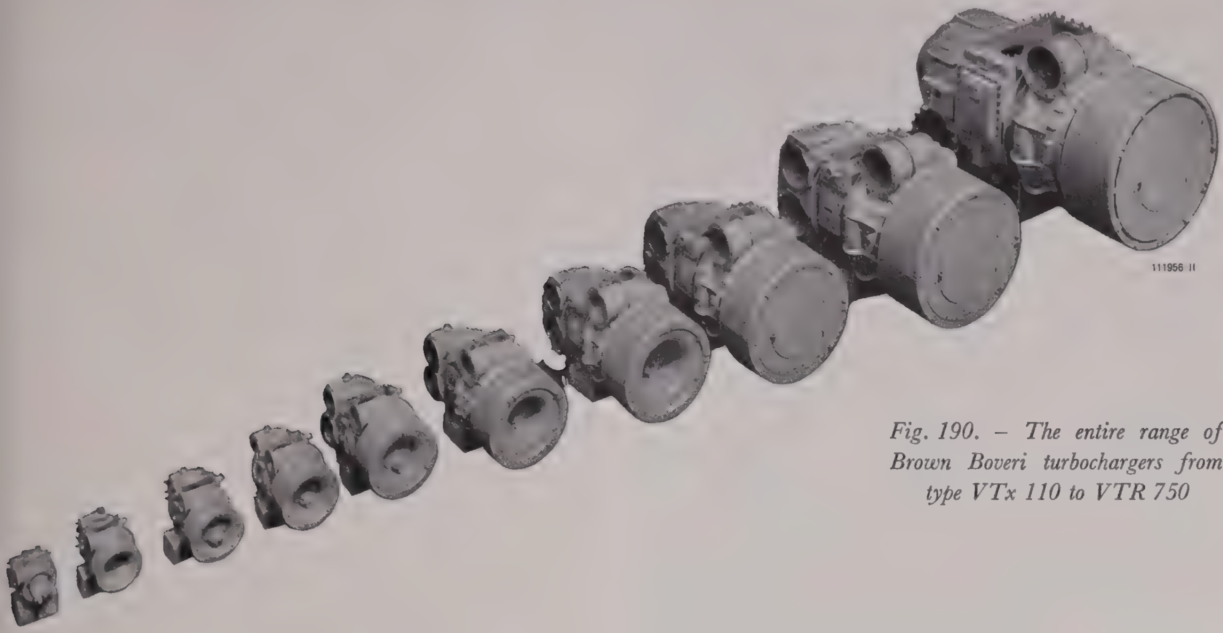

Fig. 190. – The entire range of Brown Boveri turbochargers from type VTx 110 to VTR 750

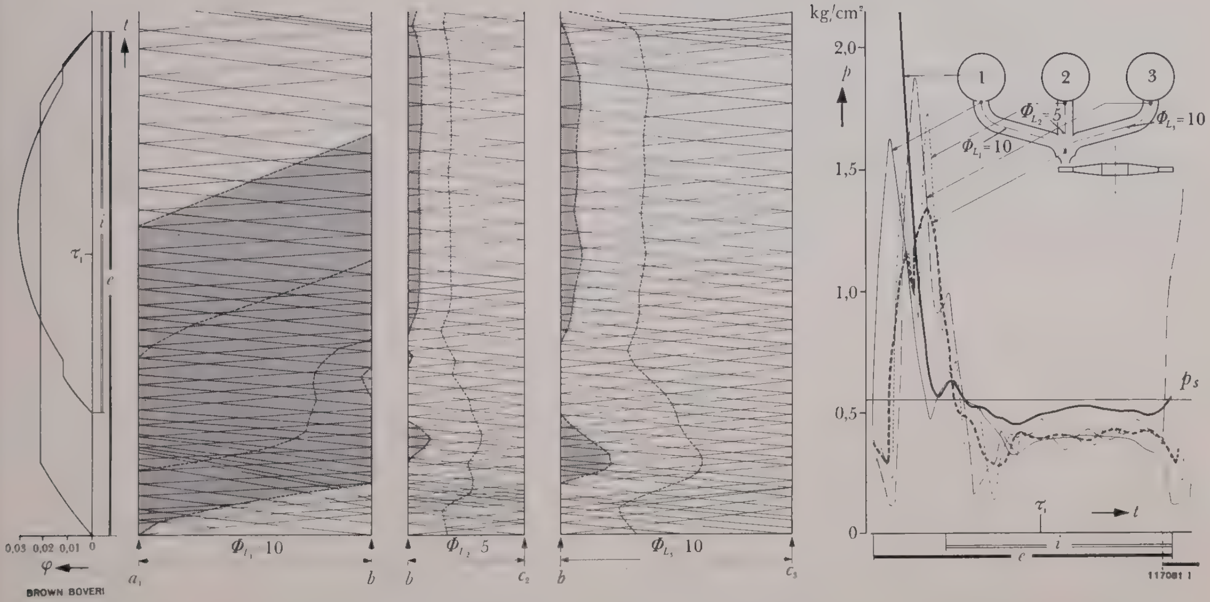

Fig. 191. – Exhaust process of a two-stroke diesel engine

The gas change from cylinder 1 is calculated by the characteristics method. From left to right: port timing, wave plans and the pressure variation in the exhaust pipes.

1 = Exhausting cylinder

2, 3 = Cylinders with closed outlet

Φ_L = Identification number for the pipe-length time expressed in degrees of crank angle needed by a pressure wave to travel the length of the pipe and back

Grey area = hot exhaust gases

t = Time

p_s = Pressure in scavenging-air tank

a_1 = Outlet from cylinder 1

b = Pipe end at the turbine

c_2, c_3 = Closed pipe ends at the cylinders 2 and 3

i = Inlet period

e = Outlet period

τ_1 = Bottom dead-centre of cylinder 1

$\varphi = f/\pi DH$ = Free-flow cross-section through the inlet and outlet valves referred to the cylinder surface area covered by the working piston πDH (where D = cylinder bore, H = stroke)

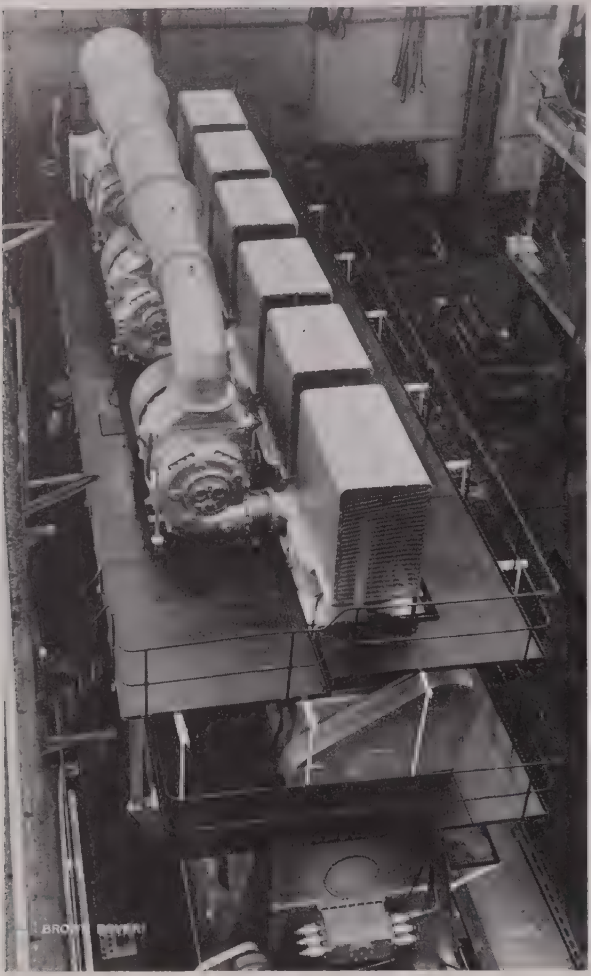

Fig. 192. – Newly developed Doxford two-stroke engine type 67 PT 6, power 10 000 bhp at 120 rev/min

50% pressure-charged with three type VTR 630 turbochargers.

Fig. 192). Also the construction of pressure-charged four-stroke engines experienced continuous progress which may not be overlooked. A special report regarding these engines will be dealt with separately in a future article.

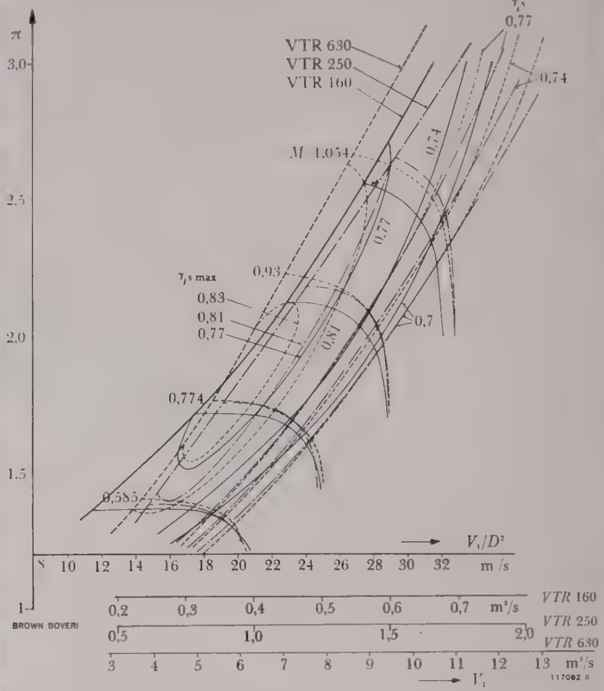

Fig. 193. – Measurements on geometrically similar compressors

In order to obtain reliable data for all turbocharger sizes, three test-beds have been installed.

The measurements from three geometrically similar compressors are shown here, superimposed on one another. The influence of the compressor size on the efficiency is clear to see. It is also evident that the stalling limit varies with the different test-beds.

π = Pressure ratio of the compressor
V_1 = Intake volume of the compressor
η_s = Isentropic efficiency of the compressor
$M = u/a_1$ (Mach number)
u = Peripheral velocity of the compressor wheel
a_1 = Velocity of the air at intake conditions

V_1/D^2 serves as a common scale for the abscissae where D = Compressor diameter.

In the endeavour to make the best use of the exhaust-gas energy from charged engines and to assure the reliability of the turbocharger, even in the face of ever-increasing demands, the chargers and their components are being continuously tested in our laboratories. The numerous measurements taken during the last few years showed, for example, the influence of the compressor size (Fig. 193). Apart from tolerance and blade thickness the compressors are geometrically alike. A decline in the efficiency is only noticeable from the size VTR 250 downwards. The reason why the stalling limits of identical machines are not exactly the same can be attributed to the fact that the three test-beds used have different piping arrangements. This proves clearly that the stalling limit of a compressor cannot be set once and for all since it is affected to a considerable extent by external factors acting on the compressor. An influence of this kind makes itself noticeable to a lesser or greater extent on every engine. The individual cylinders draw in their air periodically. This always

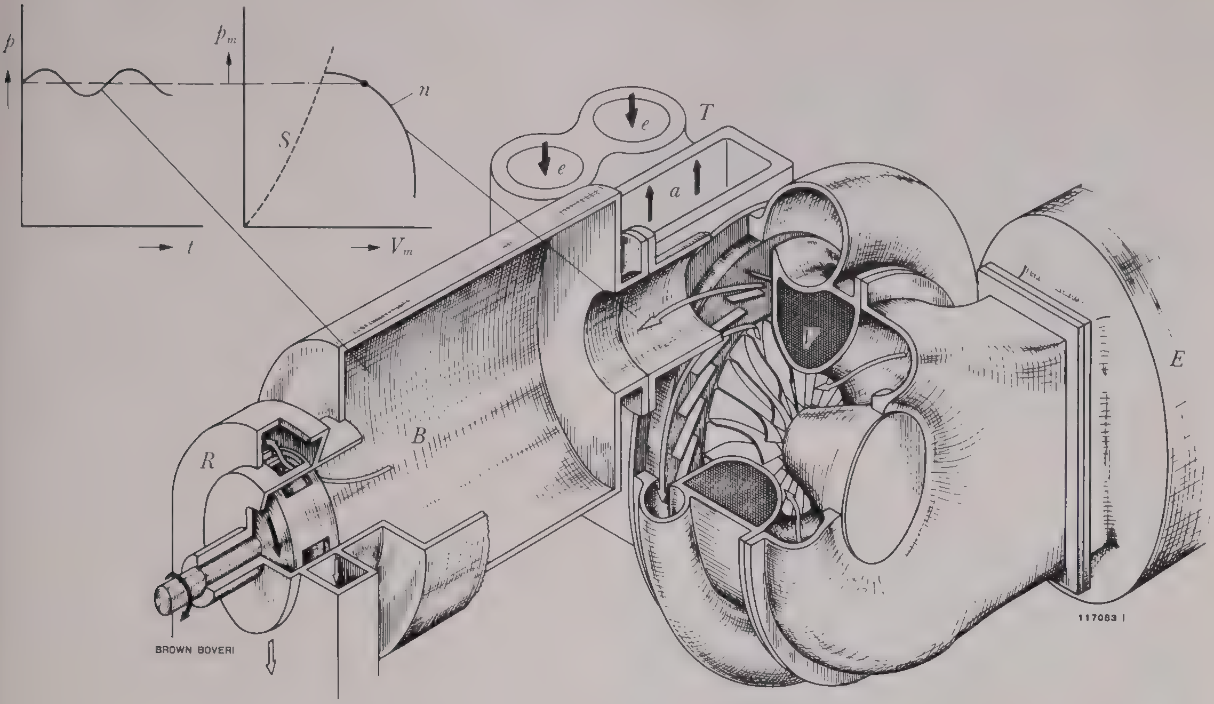

Fig. 194. – Test-rig for investigating the radial compressors of turbochargers with pulsating back pressure

With rotating valve *R*, pressure variations are produced in tank *B*, the effect on compressors *V* being investigated. (On the engine pressure variation is produced by the periodic suction of air from the scavenging-air receiver of the cylinders.)

E = Large inlet tank, where undisturbed quantity measurements can be taken
t = Time
p = Pulsating pressure
p_m = Mean discharge pressure
V_m = Mean discharge volume
S = Stalling limit
n = Compressor characteristic at constant speed
T = Turbine
e = Turbine driven by compressed air
a = Outlet of air from turbine

results in pressure fluctuation in the scavenging and charging air. Therefore, compressors must discharge against a pulsating pressure. As a result of this the stalling limit is displaced in the direction of a larger suction volume. Tests with the plant shown in Fig. 194 demonstrate that the displacement is dependent on the amplitude as well as the frequency of the pressure fluctuations.

In connection with pressure-charging by the pulsating system it was necessary to examine how the single-stage turbine of the turbocharger would function at high-pressure ratios. Above 2·5 a small drop in efficiency becomes noticeable. In the utilization of the entire exhaust-gas energy this reduction is small since merely a part of the gas is used, during the impulse peaks, at a pressure ratio over 2·5.

A high efficiency is not only required from the turbocharger when new; this condition should be maintained after a long period in operation. In any case the dirt deposits must be taken into consideration. In this connection Brown Boveri are attentively studying the relevant questions.

On the compressor side the charger becomes dirty in proportion to the filter's ability to hold back the dirt in the air. On the turbine side there are substances contained in the ash which occasionally lead to considerable deposits on the blades (Fig. 195), especially with engines running on heavy oil. It is known that heavy deposits appear in connection with high exhaust-gas temperatures. For the most part the temperatures depend on the correct dimensioning of the turbochargers. This shows the importance of

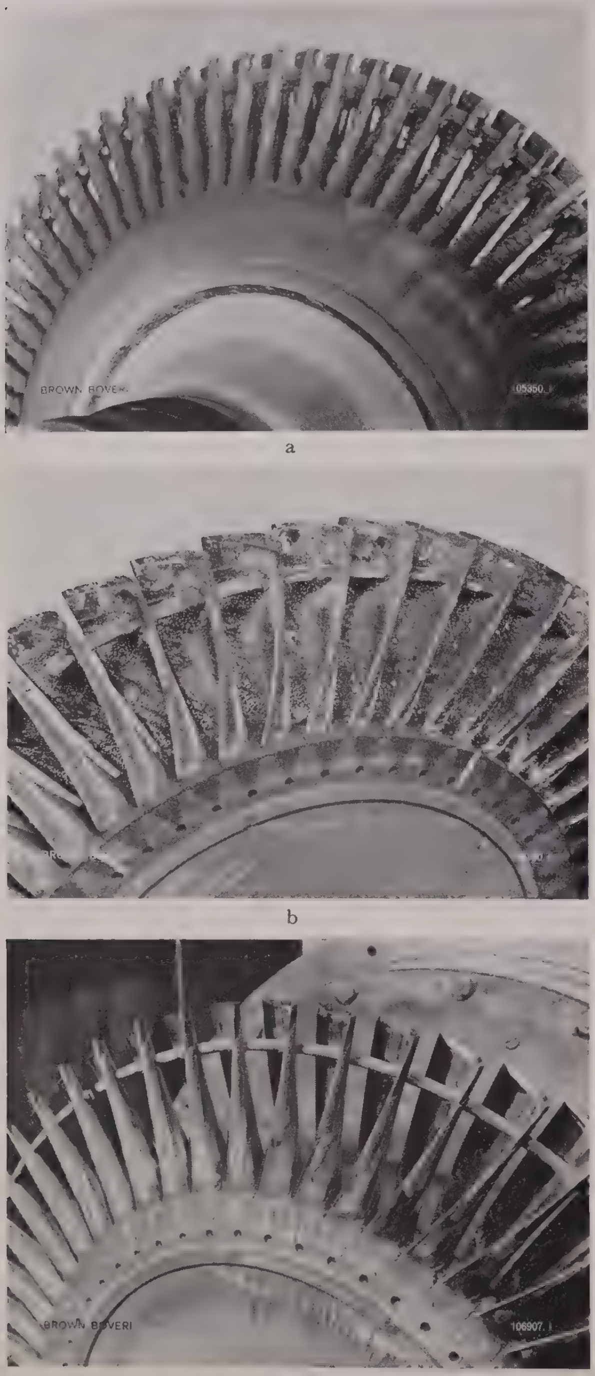

Fig. 195. – Build-up of deposits in turbocharger turbines with engines running on heavy oil

(a) Rare example of extreme deposits due to an excessively high exhaust-gas temperature

(b) In comparison with *a* the deposits here are much less. The unbalance was nevertheless quite considerable. The rotor was subsequently washed.

(c) Following washing with wet steam while in operation only about $^1/_6$ of the deposit remained; the unbalance was once more within permissible limits

correctly matching the engine and the turbocharger. In most cases washing with wet steam succeeds in substantially reducing the deposits in service. Appropriate instructions have been prepared for issuing to customers.

Even though the engine efficiency is only dependent to a small extent on the deposits in the turbocharger they produce another, undesirable effect. Since the deposits are never uniformly distributed, the rotor experiences severe unbalance. In Fig. 195 the rotor b creates a relatively good impression compared with the one in a. In spite of this, the out-of-balance load on the bearings of this rotor reaches eight times the weight. After washing, the unbalance force at 6000 rev/min was only equal to the weight of the rotor (Fig. 195c). This is a good result, although new rotors on delivery are balanced much more accurately. These circumstances show the importance of good bearing design.

The heated discussions which often took place in past years regarding the advantages and disadvantages of roller or plain bearings have eased considerably since good designs able to answer all demands are now available for both kinds of bearings. Although, as a result of the increased charging pressures, the stresses imposed are continuously growing, the operating life of roller bearings has been increased. Up to pressure ratios of roughly 1:8 it is recommended that roller bearings be changed after 8000 hours, and at higher ratios every 6000 hours. The inexpensive and reliable system of self-lubrication for roller bearings has proved a success since, under circumstances which may be regarded as normal, relatively low friction losses have to be dissipated. Only at extremely heavy loads is additional cooling of the oil or separate lubrication provided.

The favourable experience gained with roller bearings led to an analogous design for plain bearings (Fig. 196). The main part of the bearing is not held rigidly but flexibly embedded in the casing. It is surrounded by laminated springs through which oil flows, thereby damping the oscillating forces in both the radial and axial directions. This compensates for design tolerances and small assembly errors, other-

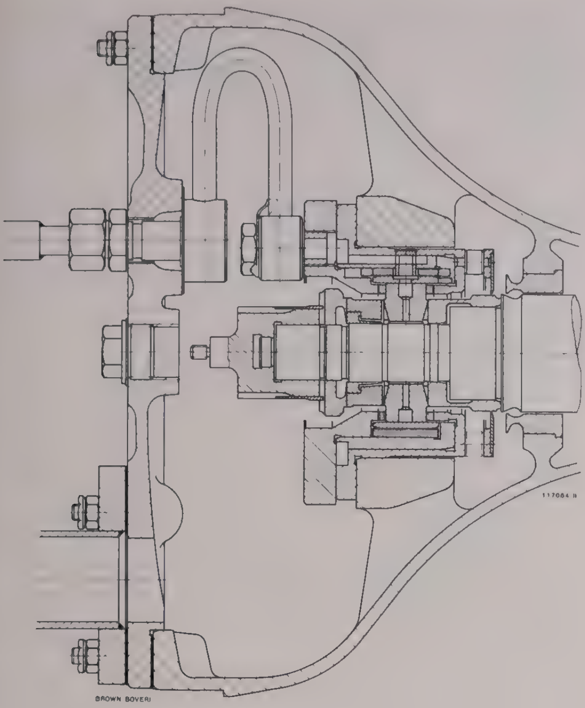

Fig. 196. – Plain bearing assembly on Brown Boveri turbochargers

Good experience gained with the flexibly-mounted shock-absorbing ball-bearings led to the adoption of a similar design for plain bearings.

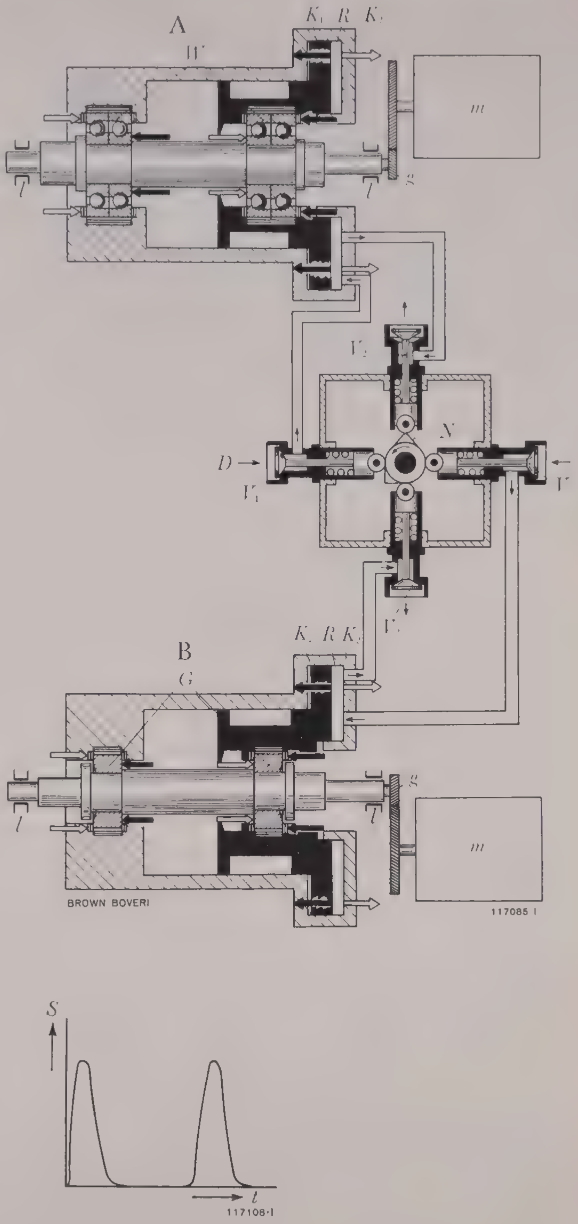

Fig. 197. – Machine for testing bearings with high pulsating axial loads

With two identical test-beds *A* and *B* tests can be performed on roller bearings *W* and plain bearings *G* under the same conditions. The axial forces are produced by introduction of compressed air *D* into the disc-shaped space *R* between the sliding pistons K_1, K_2, which are prevented from rotating. The arrows show how the forces are transferred to the bearings. The valves V_1, V_2 regulate the air intake (V_1) and exhaust (V_2).

t = Time
m = Variable-speed d.c. motors
g = Reduction gear
e = Auxiliary bearings supporting the entire set-up

wise the bearing would be forced to occupy one fixed position, where it would be liable to suffer heavy wear. Above all, owing to its damping properties, the spring-loaded bearing assembly minimizes relative motion between the rotor and the bearing, thus reducing the stresses on the bearings and helping the machine to run quietly.

Not only the unbalance forces subject bearings of exhaust-gas turbochargers to conditions differing greatly from those normally encountered. Pulsating axial thrust also produces additional stresses. This occurs with engines charged by the pulsating system. Here gas pressures with peaks up to 3 bar are produced at the turbine inlet. In order to fundamentally clarify the question connected with such bearing loadings a test bed as shown in Fig. 197 was put into operation.

To assess the effect of mechanical stresses on machine parts it is frequently not possible to rely

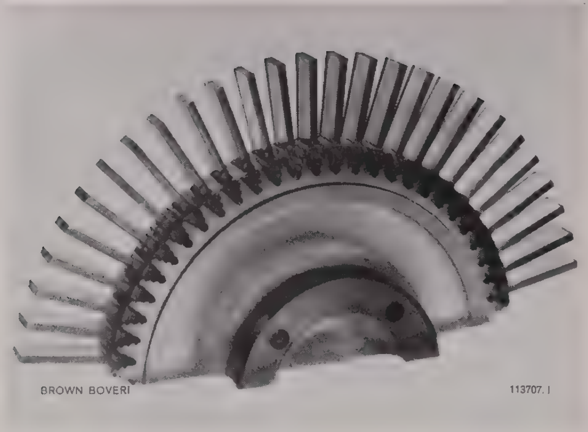

Fig. 198. – Synthetic resin model used for photoelastic stress measurements on the turbine discs of a turbocharger

The stress-freezing method was employed for this investigation, the model being rotated at constant speed and elevated temperature. By slowly cooling to room temperature it was possible to reproduce the state of strain caused by rotation and to fix the photoelastic effect. The internal stresses are then retained after the external load has been removed from the model. The model can even be sectioned without effecting the solidified stress field.

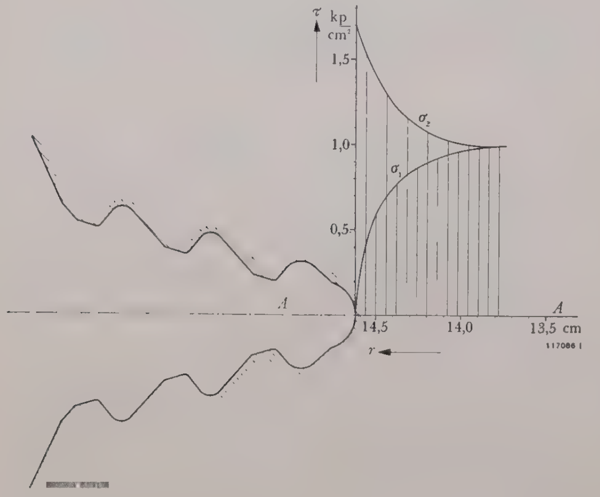

Fig. 200. – Numerical evaluation of the photoelastic pattern shown in Fig. 199. Principal stresses along section A-A

$\sigma_{1,2}$ = Principal stresses
r = Radius of turbine disc

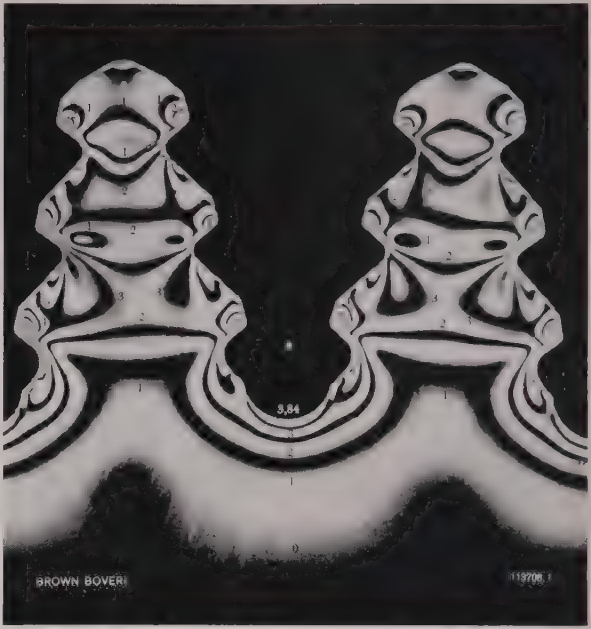

Fig. 199. – Isochromatic pattern of the turbine disc model in Fig. 198

After being loaded, heated and cooled, a plane-parallel section was cut from the model. By passing polarized light through the specimen, lines of equal shear stresses appear. They not only provide an instructive picture of the stress distribution but also permit an exact numerical evaluation. The numbers inserted in the picture show the isochromatic order, from which, with the help of material constants, the principal stresses can be determined.

solely on determination of a nominal stress. Much more attention must be paid to the way in which the stresses are distributed. However, owing to the form of most workpieces it is impossible to determine the stress distribution accurately enough, even using the most complicated methods of calculation. Of the various methods used in experimental stress analysis, the photoelastic method has proved particularly successful. With the help of the stress-freezing method, dynamic and three-dimensional stresses can also be rendered visible. Brown Boveri have employed this method in their own laboratories to test the turbine discs of exhaust-gas turbochargers. Among other interesting problems the increase in the stresses imposed on the turbine wheel by the fir-tree profile of the blade fastenings was studied. A three-dimensional model (Fig. 198) of the wheel with assembled blades was dealt with according to the stress-freezing method. Fig. 199 shows a cross-section through the model in the tangential direction. The principal stresses which appear along the line *A–A* are illustrated in Fig. 200.

VI. TRACTION

Some noteworthy new designs have been brought out to enrich the field of electric railway traction. In the sphere of single-phase traction at $16^2/_3$ c/s successful progress was made, culminating in the high-power motor-coach carrying passengers and luggage. In traction vehicles fed with a.c. at industrial frequency, a firm position has been established by semiconductor rectifiers—especially those using silicon. Continued development of this principle will probably form one of the main tasks during the next few years. Close attention was also devoted to the problems associated with the design and construction of multi-system vehicles, for which a number of interesting solutions have been devised. Even on the classic d.c. locomotives new designs of control gear and resistors have helped in the battle to reduce weight. Similar progress was also apparent in diesel-electric vehicles, where there has been a pronounced demand for higher powers. As regards trams and trolleybuses, the main interest has been centred round the articulated types of vehicles. Modern electronics are gaining an increasing hold in the traction world, particularly in control systems, where interesting possibilities are offered. A point which must not be overlooked is the incessant effort to improve the adhesion between rail and wheels, which is a key factor in the endeavours to increase the capacity of the country's railways still further.

A. Traction with $16\,^2/_3$ c/s A.C.

Having taken delivery of 24 more $C_0'C_0'$ locomotives of the well-known Ae 6/6 series, the Swiss Federal Railways now possess 50 of these well-tried, powerful locomotives (Fig. 201). Orders for 24 more were placed with Swiss manufacturers in July 1960. The fact that the specification for these agreed almost

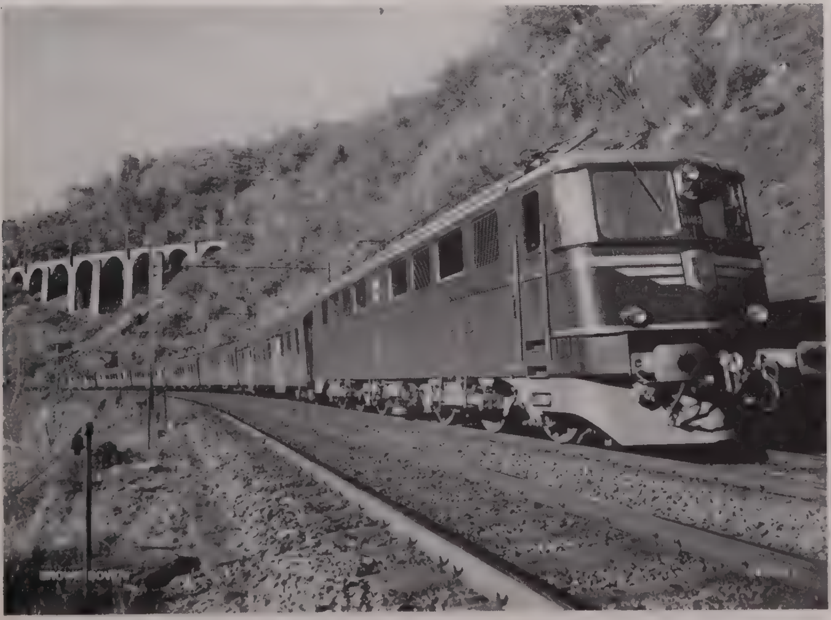

Fig. 201. – At the head of one of the Gotthard express trains, this Ae 6/6 locomotive speeds down the valley near Giornico

Fifty locomotives of this type are carrying out their arduous duties on the Gotthard and Simplon routes. An order for 24 more was placed during the summer of 1960.

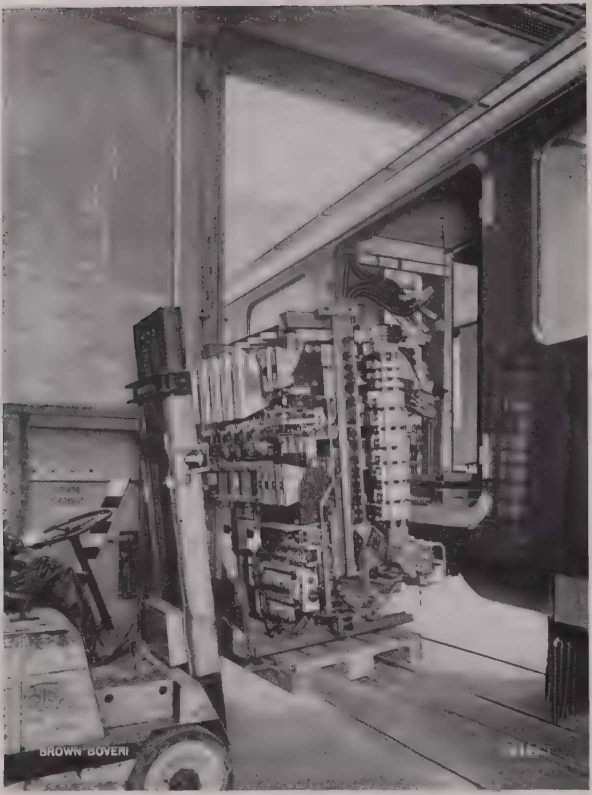

Fig. 202. – Insertion of the ready-assembled and wired control gear block in the compartment provided for it in the RBe 4/4 motor-coaches of the Swiss Federal Railways

At the top of the front are the four isolating contactors and the two changeover contactors. In the middle are the current transformers for the traction motors and the load-switches of the tap changer, with the driving mechanism of the latter below, complete with control valves and auxiliary contacts. The rear of the frame is occupied by the vertically mounted reversing and braking switch.

word for word with that for the previous batches, may be viewed with considerable satisfaction by the original designers of these locomotives—the Swiss Locomotive and Machine Works (SLM) and Brown Boveri.[1]

The vehicle park of the Berne–Lötschberg–Simplon Railway Company was augmented by a new double locomotive with the axle sequence $B_0'B_0' + B_0'B_0'$.[2] The design of this vehicle, which was built in collaboration with SLM, closely resembles that of the successful Ae 4/4 locomotives of the same undertaking. The increased traction motor output, totalling 6450 kW, allows trains weighing up to 900 tons to be hauled at speeds of 70–75 km/h up the steep gradients of the Lötschberg line without assistance from a second locomotive. Their top speed is around 125 km/h. The excellent results obtained with the first of these locomotives induced the BLS to order a second during the summer of 1960.

The construction of motor-coaches is represented by a number of high-output units.[2] They perform the traction duties of light locomotives and, at the same time, provide facilities for the transport of passengers and parcels or luggage. At this point reference may be made to the six motor-coaches type RBe 4/4 purchased by the Swiss Federal Railways, for which Brown Boveri supplied the current collectors, air-blast circuit-breakers, transformers, the entire control system with low-voltage tap changers, and the spring drives. Fig. 202 shows the insertion of the control gear assembly in compartments specially provided for the purpose in the body of the vehicle. These motor-coaches, in conjunction with six driver-trailers ordered at the same time, are used to haul important train compositions in an express inter-urban shuttle service, covering up to 1300 km daily.

Three motor-coaches of similar design were supplied to the Schweizerische Südostbahn and the Bodensee–Toggenburg Railway. In this case the coachwork was provided by the Swiss Industry Co., with electrical equipment manufactured and installed by Brown Boveri. The four traction motors produce a one-hour tractive effort at the wheel rim of 10 500 kg, which corresponds to a power output of 1575–2060 kW in the speed range from 55 to 72 km/h. The top speed is 110 km/h. The motor-coaches, which are ideal for combination with driver-trailers to form shuttle-service compositions, have proved an extremely efficient means of handling the heavy traffic between north-east and central Switzerland, with its heavy winter sports and summer tourist traffic, as well as carrying the visitors to the famous shrine in Einsiedeln.

The Company's concessionaires have also been active in the field of railway traction. Brown Boveri, Mannheim, for instance have supplied 40 more lightweight $B_0'B_0'$ locomotives of the E 41 class to the Federal German Railway, the total number of which has now risen to 148 units.[3] The Austrian Brown Boveri works have completed five further $C_0'C_0'$ locomotives of the 1110 series for the Federal Austrian Railway, in addition to supplying numerous items of equipment, such as airblast circuit-breakers, transformers, tap changers and spring drives. The Norwegian State Railways have received six lightweight locomotives of the EL 13 class, as well as various other items of equipment, made by Norsk Elektrisk & Brown Boveri in Oslo.

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[1] E. HUGENTOBLER: The electric $C_0'C_0'$ locomotives, series Ae 6/6, of the Swiss Federal Railways. Brown Boveri Rev. 1956, Vol. 43, No. 8, p. 301–17.

[2] E. ISLER: New locomotives and motor-coaches for single-phase supplies at $16^2/_3$ c/s. Brown Boveri Rev. 1960, Vol. 47, No. 9, p. 571–81.

B. 50-c/s Traction and Multi-System Vehicles

Traction with alternating current at the industrial frequency of 50 c/s has continued to gain in importance, having attracted widespread attention. At an early stage the superiority of rectifier locomotives over vehicles with rotating converters or directly-driven motors was generally recognized. Whereas formerly it was common practice to employ mercury-arc rectifiers of the ignitron or excitron type, there is now a marked tendency to go over to semiconductor rectifiers, especially silicon diodes. Brown Boveri have now entered this market with products of their own manufacture.

An interesting vehicle which deserves mentioning is the three-system locomotive of the Swiss Federal Railways, for which Brown Boveri supplied the electrical equipment.[4] The mechanical part, with the axle sequence $(1\,A_0)\,B_0\,(A_0\,1)$, dates back to 1941, when it was used for the first gas-turbine locomotive to be built by Brown Boveri, in which form it justifiably attracted considerable attention. However, with the progressive electrification of the Swiss railway

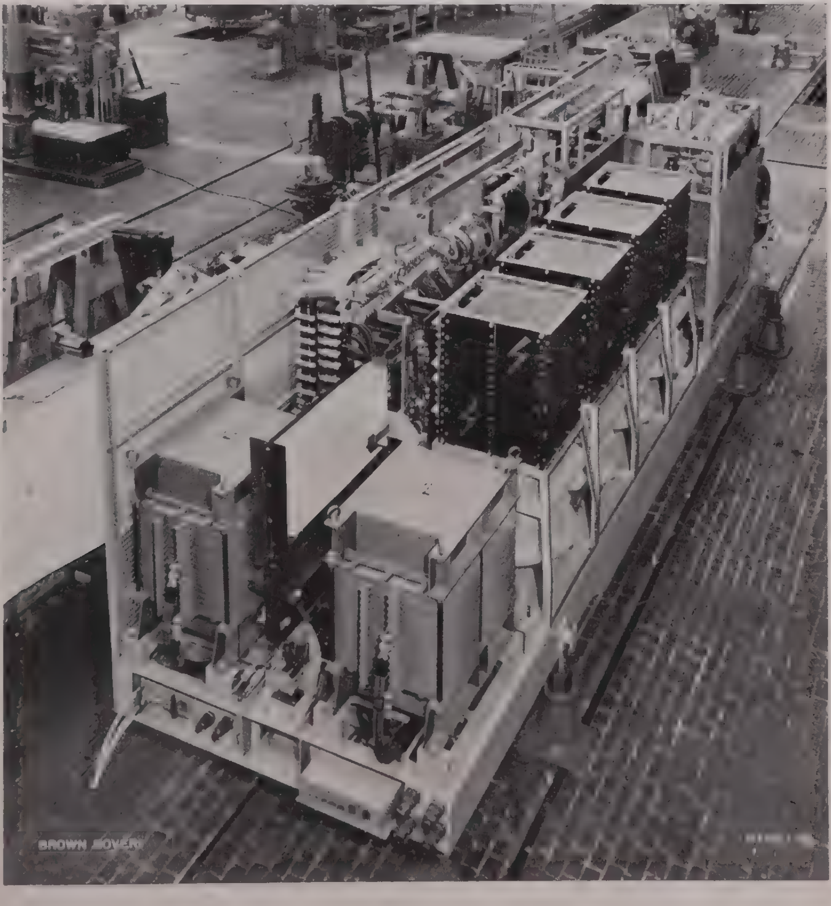

Fig. 203. – Control gear block ready for assembly in the three-system locomotive type Ae 4/6 III of the Swiss Federal Railways

With the exception of the equipment mounted on the roof, the traction motors and the driver's stand, all items of electrical equipment are mounted on a strong framework, attached to the locomotive frame at three points.

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[3] H. Käfer: Neue elektrische Triebfahrzeuge der Deutschen Bundesbahnen. BBC Nachrichten, 1957, Vol. 49, No. 1, p. 6–18.

[4] E. Kocher: 50-c/s and multi-system traction. Brown Boveri Rev. 1960, Vol. 47, No. 9, p. 582-97.

network, it ceased to be economical. The four self-ventilated traction motors and spring drives were retained, while the thermo-electric power unit was replaced by an all-electric system, capable of running on supplies of 15 kV, $16^2/_3$ c/s, or 25 kV, 50 c/s, as well as 1500 V d.c. In the latter case starting is controlled by cam-operated resistors, permitting series and series-parallel grouping of the motors. For single-phase operation a transformer with h.v. tap changer is provided, which feeds the four bridge-connected banks of silicon rectifiers, each belonging to one traction motor. Smoothing chokes reduce the pulsation of the current. In order to simplify the modification of the mechanical part of the locomotive as far as possible, all the electrical equipment was mounted on a framework resembling the chassis of the gas-turbine set, enabling it to be assembled and wired before insertion in the vehicle body. Fig. 203 shows the supports with the assembled electrical equipment, ready for insertion in the vehicle. Having regard to the purpose for which the vehicle was originally built, the one-hour rating of the traction motors is rather low at 1760 kW for a speed of 83 km/h. As a result of the conversion, the weight of the vehicle has been reduced from 108 t to 80 t plus 4 t ballast, giving an axle pressure of 16 t.

A two-frequency locomotive for $16^2/_3$ and 50 c/s was supplied in the summer of 1960 by Brown Boveri, Mannheim, to the Federal German Railway. Its mechanical part originates from one of the well-known E 10 locomotives. Of the electrical equipment the airblast breaker, transformer, h.v. tap changer and the equipment for the electronically controlled rheostatic brakes were built by Brown Boveri. The four traction motors, rated 630 kW each (one-hour), were produced on a joint basis by the leading German manufacturers of traction equipment. The speed corresponding to the one-hour output of the locomotive, which is known as the E 320.11, is stated to be 64·6 km/h, with a top speed of about 120 km/h.

C. D.C. Traction

A representative object from the field of d.c. traction is the 9400 class of lightweight locomotives of the French National Railways (SNCF), for which the Compagnie Electro-Mécanique, Paris, contributed all the electrical equipment with the exception of the traction motors and current collectors, in addition to undertaking the layout design work. The locomotives, which are equipped with single-motor bogies (Fig. 204) and are therefore classed as B′B′, have a tare weight of 60 t. The one-hour output of 2300 kW is produced at a speed of 48·5 km/h, while the top speed amounts to about 130 km/h. The two traction motors remain parallel connected, even when starting, thereby reducing the tendency to slip. The resistors are of the new Brown Boveri vane-type design,[5] and consequently compact and light, and are cooled by an intensive forced draught. They are switched in 28 stages by means of an electro-pneumatically operated system consisting of selector and load switches. Owing to the lightness and the small space occupied by the latter, this new control system is notable among new designs. Despite the short axle spacing of the bogies, only 220 cm, the locomotive has excellent running properties. The French Railways intend to purchase a total of 116 of these units.

The Swiss electrical industry and coachbuilders supplied a second group of five three-part multiple-unit trains for the Spanish State Railways (RENFE). They run off a supply of 3000 V. These trains, comprising two motor-coaches having a one-hour rating of 1030 kW each, and an intermediate trailer coach, are employed on the suburban lines in the Barcelona area, where they are rendering splendid service. The construction of these vehicles by Spanish firms under licence is now in full swing.[6]

On the narrow-gauge Centovalli line running between Locarno in southern Switzerland and Domodossola in Italy, four new three-coach trains with electrical equipment for 1300 V supplied by Brown Boveri workshops in Baden and Milan have been in service since the spring of 1959.[7] With a tare weight of only 59 t, these trains have seating accommodation for 113 passengers. Four traction motors

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[5] E. SCHOCH, A. GRASSET: Vane-type resistors. Brown Boveri Rev. 1960, Vol. 47, No. 9, p. 566–70.

[6] F. SAEZ: New multiple-unit stock for the Spanish State Railways (RENFE). Brown Boveri Rev. 1960, Vol. 47, No. 9, p. 626-32.

[7] W. ZBINDEN: Traction vehicles for local services. Brown Boveri Rev. 1960, Vol. 47, No. 9, p. 610–25.

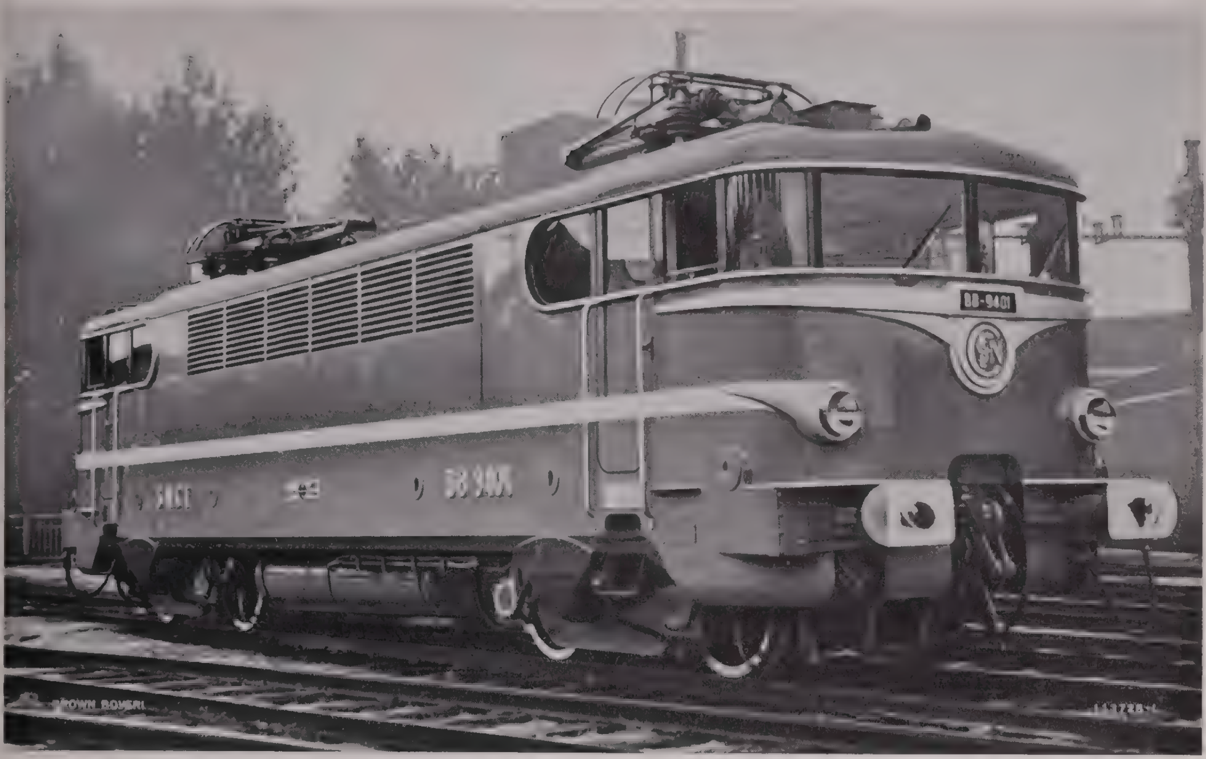

Fig. 204. – B′B′ d.c. locomotive of the 9400 class of the French National Railways (SNCF)

One-hour rating 2300 kW at 48·5 km/h; top speed 130 km/h. The low total weight of 60 t was attained primarily by incorporating various new lightweight designs of Brown Boveri.

mounted in the longitudinal direction produce a one-hour ouptut of 360 kW at 43·5 km/h. Their torque is transmitted to the driving axles by Cardan shafts and hypoid gearing. Starting is semi-automatically controlled by electro-magnetic contactors.

In 1959 Brown Boveri, Mannheim, supplied the electrical equipment for sixteen multiple units of the Hamburg overhead railway. These trains, which run off 1200 V, contain a new feature in their control gear: an electronic circuit which varies the switching rate in terms of the motoring and braking current.[8]

D. Diesel-Electric Traction

The electrical method of transmitting the power of the diesel engine to the wheels continues to assert itself, in spite of the intensive progress in the development of the hydraulic system. It is encountered in small, industrial shunting engines, as well as in high-powered main-line locomotives. There is, however, a marked tendency to increase the power of the engines, while keeping within the limits imposed by the stipulated load per axle. This increase necessitates consistent efforts to achieve light constructions, combined with careful co-ordination of the mechanical, electrical and thermal requirements.

The Swiss Federal Railways ordered 10 $C_0'C_0'$ diesel-electric locomotives of the type Bm 6/6. This unit, which was designed and developed between 1952 and 1954—four units being built in that period[9] —is illustrated in Fig. 205. The latest locomotives are being built practically unchanged, except that silencing the exhaust has been appreciably improved. Each has two diesel-electric units with an 850-hp engine, which can be run together or separately. The six nose-suspended traction motors enable the

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[8] W. STEIN: Die Fahr- und Bremsstromregelung der Triebzüge ET 170 der Hamburger S-Bahn. BBC Nachr. 1960, Vol. 42, No. 12, p. 573–80.

[9] E. M. KLINGELFUSS: New diesel-electric locomotives for the Swiss Federal Railways. Brown Boveri Rev. 1958, Vol. 45, No. 3, p. 142–6.

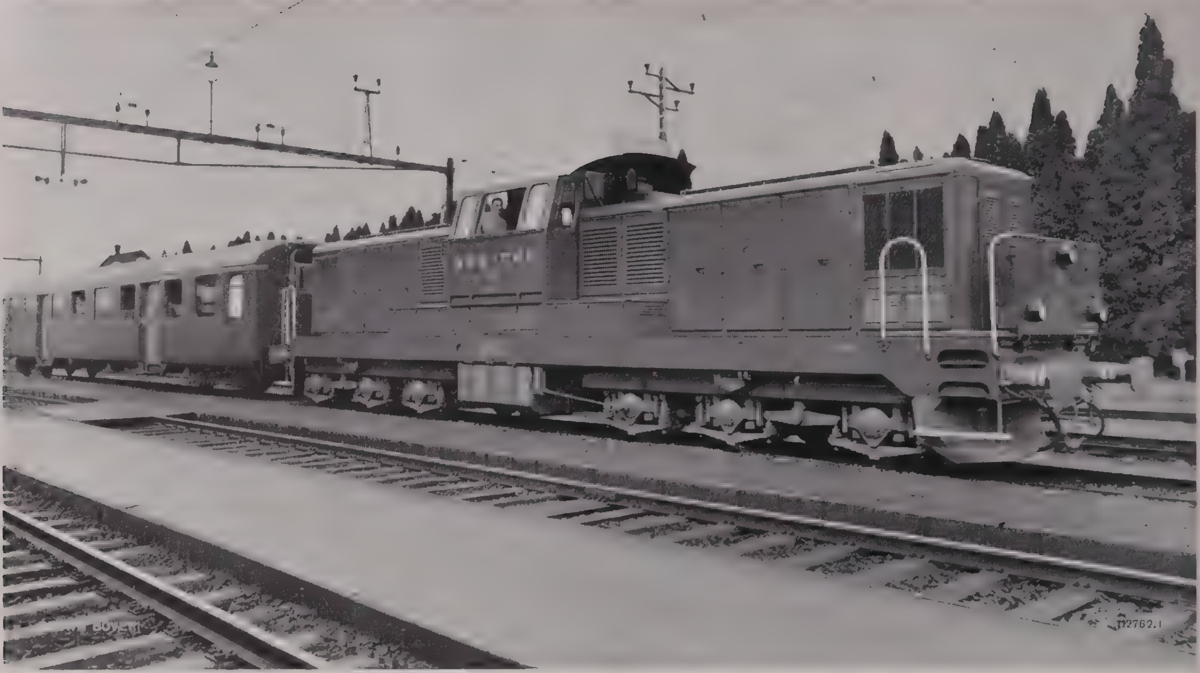

Fig. 205. – Type Bm 6/6 diesel-electric locomotive of the Swiss Federal Railways, for heavy shunting and main-line traffic

The two superstructures adjoining the central driver's cab each contain a 850-hp diesel-electric power unit.

locomotive to develop a continuous tractive effort of 15 000 kg at 20 km/h and 33 000 kg when starting. Since these locomotives, whose tare weight is 112 t, are not only intended for heavy shunting duties, but also for main-line traffic, they have a top speed of 75 km/h. Their manufacture is a joint concern of a number of Swiss locomotive, diesel engine and electrical firms, among whom Brown Boveri are responsible for all the traction and auxiliary motors, the greater part of the control gear, plus a major share in the erection of the equipment.

In Finland and Roumania, $C_0'C_0'$ diesel-electric locomotives are now being built under licence to the designs prepared for the prototype models made in Switzerland. The state-owned railways in both countries plan the procurement of large numbers of these new locomotives which, with respective outputs of 1900 and 2100 hp, are very powerful vehicles.[10]

The Company's concessionaires in France, the Compagnie Electro-Mécanique (CEM), were also active in the field of diesel-electric traction. Among their main achievements are the 90 $B_0'B_0'$ locomotives of the 040 DG class ordered by the SNCF, with diesel engines from various manufacturers and with outputs of 1200, 1400 and 1750 hp. The electrical equipment of these locomotives, which have a uniform tare weight of 72 t, was supplied by CEM, except for the traction motors and reversing switches.

Prominent among the motor-coaches are the ten "autorails panoramiques" of the X 4200 class, equipped with an 800-hp diesel engine, also supplied to the SNCF. These units have a top speed of 130 km/h. Developed by CEM and Renault in close collaboration, they provide accommodation for 88 passengers. The raised first-class compartment, in addition to affording an excellent all-round view, simplifies the installation of the machinery and the numerous auxiliaries.

In addition to the large objects referred to above, CEM also supplied numerous small two, three and four-axle shunting engines and goods locomotives with outputs ranging from 180 to 800 hp.

Tecnomasio Italiano Brown Boveri have also had some noteworthy orders for diesel-electric traction vehicles. A series of 20 $B_0'B_0'$ locomotives with an engine output of 1320 hp, built for the Italian State Railways, is particularly interesting. Another for 29 units rated 700-hp with the same axle sequence is at present on hand.

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[10] A. FEDDERSEN: Diesel-electric traction. Brown Boveri Rev. 1960, Vol. 47, No. 9, p. 598–604.

E. Trams and Trolleybuses

In the construction of trams, attention is concentrated on increasing the passenger-carrying capacity while minimizing the outlay for operation and maintenance. These conditions have been fulfilled by the development of articulated vehicles having a much larger capacity but requiring no more crew. In Switzerland the municipal transport undertakings in Basle and Zurich have followed this trend and have taken delivery of three six-axle articulated trams altogether. As far as the coachwork is concerned, these are all very similar (mechanical equipment supplied by the Swiss Industry Co.), whereas the electrical equipment supplied by Brown Boveri includes four traction motors per tram for Basle, but six for Zurich. These are controlled by electro-magnetic contactors, which not only establish the circuits for the two directions of travel, but also for regenerative braking. With unladen weights of 24 t (Basle) and 28·5 t (Zurich), respectively, these vehicles can carry 165 passengers. The motors—4 × 66 and 6 × 66 kW—enable them to accelerate rapidly and achieve top speeds of up to 60 km/h.

Equipments for articulated trams were also supplied in large numbers by Brown Boveri, Mannheim, to the towns of Mannheim and Heidelberg (Fig. 206). A feature of these vehicles is that they only utilize one 120-kW traction motor in each of the end bogies, which, in conformity with current German practice, are equipped with a compensating winding. The control of the starting and braking resistors, and the series and parallel grouping of the motors, is performed by a cam-type controller.

Articulated vehicles have also attracted great attention in Italy, where Tecnomasio Italiano Brown Boveri have supplied 18 four-motor articulated trams for the City Transport Authority in Milan.

At home in Switzerland eight trolleybus equipments have been supplied to the Winterthur Corporation, for use in four-wheel vehicles. These are of a design suited to the conditions in this country and exhibit the following characteristic features.[11] They have a double-commutator motor with a one-hour output of 100 kW, electro-magnetic contactor control, the elements of which are combined with the remaining apparatus to form a block; the energy dissipated in the resistors is utilized for heating the bus.

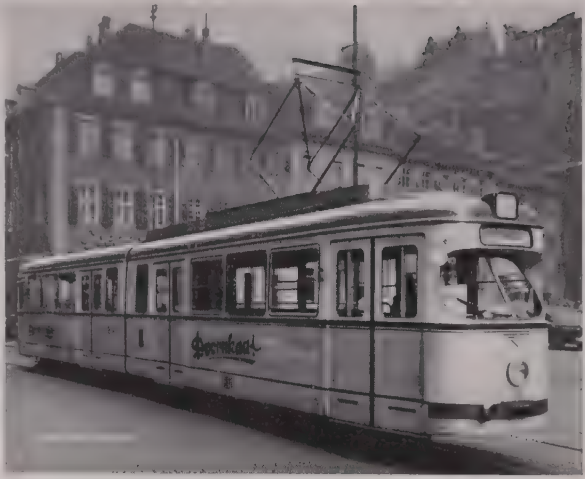

Fig. 206. – Six-axle articulated tram-car of the Heidelberg Transport Undertaking (Germany)

A traction motor with a one-hour output of 120 kW is mounted longitudinally in each of the two end bogies and drives the axles through hypoid gearing. Tare weight 19 t; accommodation for 171 persons.

In view of the heavy traffic anticipated in Lausanne during the National Exhibition due to take place in 1964, the City Transport Authority has ordered 22 new four-wheel trolleybuses with a motor rating stepped up to 130 kW, all equipped by Brown Boveri.

In Austria, trolleybuses have been supplied to the city of Linz by the Brown Boveri works in Vienna; likewise in Italy, numerous undertakings have ordered trolleybuses from Tecnomasio Italiano Brown Boveri.

F. Mountain Railways

The ever-increasing requirements of tourist traffic and the efforts of numerous mountain railway undertakings to modernize their out-dated vehicle park have led to many orders for new vehicles in recent years.

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[11] W. ZBINDEN: Simplified control unit for trolleybuses. Brown Boveri Rev. 1958, Vol. 45, No. 10, p. 493–4.

For instance, in the last two years, numerous orders were placed for vehicles which were repeats of well-known and tried designs. The following may be quoted as typical:[12]

- Four single-motor rack motor-coaches for carrying passengers and luggage, complete with uphill-side driver-trailer, for the metre-gauge Jungfrau Railway; supply 1125 V, 50 c/s; tare weight 23·5 t, seating accommodation 45; one-hour traction motor rating, 440 kW at 11·4 or 22·8 km/h.
- Four twin-motor rack motor-coaches for carrying passengers and luggage, for the metre-gauge Gornergrat Railway. Supply three-phase 750 V, 50 c/s; tare weight 17·3 t; seating accommodation 56; one-hour rating of traction motors 2 × 96 kW at 14·5 km/h.
- Two four-motor rack motor-coaches for carrying passengers and luggage, for the Wengernalp Railway; supply 1500 V d.c.; gauge 80 cm, tare weight 23·5 t; 44 seats, 1st and 2nd class; one-hour rating of the traction motors 4 × 110 kW at 17·8 km/h.

In addition to these railway vehicles, numerous sets of electrical equipment have been supplied for aerial ropeways and ski-lifts.

For modernization of the rack and adhesion line Hergiswil, Stansstad, Engelberg, and its conversion from three-phase to single-phase a.c. at $16^2/_3$ c/s, Brown Boveri have been entrusted with the electrical equipment for five three-coach shuttle-service compositions.

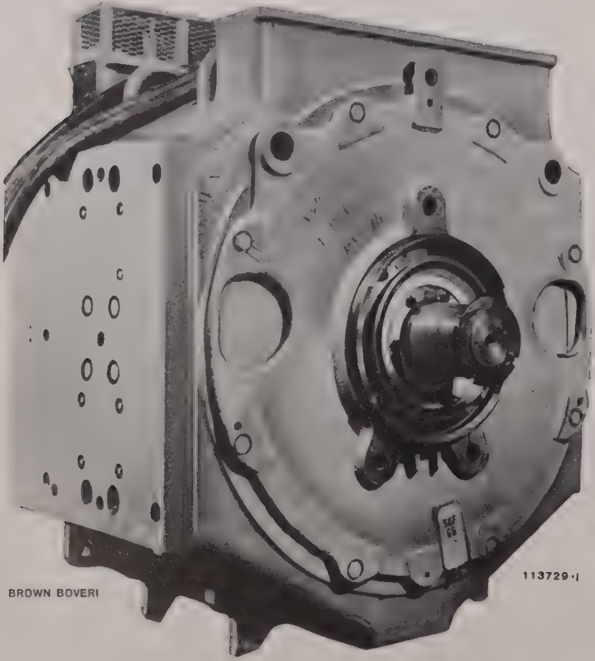

Fig. 207. – Six-pole, self-ventilated pulsating-current traction motor

One-hour rating 750 kW at 775 rev/min; supply voltage 850 V; top speed 2080 rev/min. This type of motor is used in the single-motor bogies of a.c. motor-coaches for the service in the northern suburbs of Paris, operated by SNCF.

G. Separate Items of Equipment

Apart from preparing the layout, constructing and carrying out the erection of traction vehicles, an important share of the Company's business in this sphere involves the supply of individual items of equipment. Particularly when very large contracts are involved, it proves expedient to distribute the manufacture of the various elements among a number of firms, thereby making better use of each one's production capacity.

For fitting to locomotives and motor-coaches the traction-type airblast circuit-breaker type DBTF for 15 and 25 kV, with breaking capacities of 200 or 250 MVA, has been constantly in demand, as in previous years. The excellent results gained are clearly borne out by the fact that British Railways have so far ordered 500 of these breakers from Brown Boveri.

A new locomotive breaker rated 100 MVA at 15 kV has been specially designed as a roof bushing for use on motor-coaches. The first batch of 25 will shortly be delivered to the Swiss Federal Railways.

In the field of tap changers for locomotive control the Company have maintained their leading position with the well-known models. For instance, 117 units for 15 kV, with a rated sustained current of 220 A, and with 40 positions, were supplied to the Indian Railways. The newly developed 25-kV tap changer, rated 400 A, for high-voltage control has now been released for manufacture.[13] The first of these have already been supplied to the Berne–Lötschberg–

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[12] E. HUGENTOBLER: Modern traction vehicles for mountain railways. Brown Boveri Rev. 1956, Vol. 43, No. 1, p. 28–48.

[13] W. BILLETER: High-voltage tap changers for a.c. locomotives. Brown Boveri Rev. 1960, Vol. 47, No. 9, p. 549–55.

Simplon line (BLS). Seventy more have been built by our French concessionaires, mostly for employment under severe operating conditions.

Among traction motors, one which deserves special mention is the prototype pulsating-current motor with a one-hour output of 750 kW at a rated voltage of 850 V and a speed of 775 rev/min. It is intended for incorporation in the single-motor bogies of new suburban motor-coaches for the SNCF. Fig. 207 shows the appearance of the six-pole, compensated, self-ventilated motor, which stood up extremely well to the comprehensive and exacting type tests to which it was submitted by the client.

Mention may also be made of warm-air heating installations for long-distance trains, equipped with thermostatic temperature control and automatic switchover to the supply voltages 1000, 1500 and 3000 V, which have been supplied in quantity to the Swiss and various foreign railway authorities.[14] In addition to providing the special current collectors,[15] the airblast breakers and spring drives for four new Trans-Europe Express trains ordered by the Swiss Federal Railways, Brown Boveri are also supplying the complete air-conditioning plant, including the warm-air heating system.

In conclusion, attention may be drawn to a field in which Brown Boveri have gained a considerable amount of success, and which has given a strong impetus to diesel-electric traction, namely the use of turbochargers to increase the power output of diesel engines. Fig. 208 shows the diesel-electric set of one of the $C_0'C_0'$ locomotives for Finland, as described in section D. As a result of pressure-charging, the torque and power output of the engine can be nearly doubled. The possibilities which this affords are most obvious in the traction sphere, in view of the constant efforts being made to obtain more powerful, but lighter thermo-electric power units.

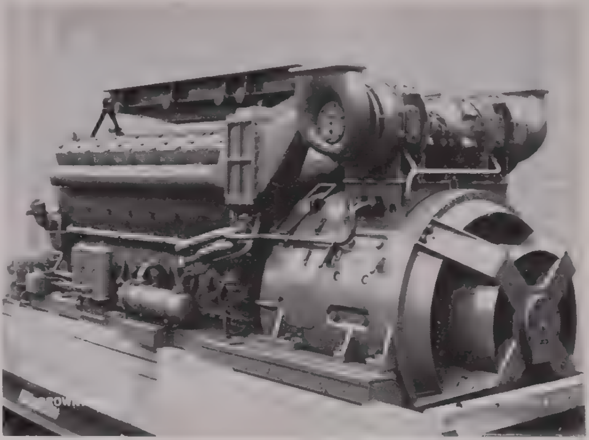

Fig. 208. – Diesel-generator set built by MAN and Brown Boveri for an output of 1900 hp, with turbo-charger and charging-air cooler, fitted to the $C_0'C_0'$ locomotives of the Finnish State Railways

The effect of turbocharging is to almost double the power of the diesel engine.

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[14] F. Thomann: Air-conditioning equipment in railway vehicles. Brown Boveri Rev. 1960, Vol. 47, No. 9, p. 633–39.

[15] A. Fehr, R. Keller: Pantograph current collectors for high speeds. Brown Boveri Rev. 1960, Vol. 47, No. 9, p. 561–6.

VII. HIGH FREQUENCY

A. Electron Tubes

During the past two years more customers than ever have taken an interest in our electron tubes, the result of which has been an increased turnover for all types.

It is becoming more and more evident that, particularly the apparatus manufacturers in the industrial sphere not only desire to purchase tubes, but that they also place great value on technical advice regarding their application. Our applications laboratory, which was specially established to assist clients in this respect, has therefore been extended and equipped with modern measuring equipment so that in the future it will be able to answer questions posed, as a result of the practical experience gained in the meantime.

1. Transmitting and Industrial Tubes

The range of convection-cooled transmitting tubes was extended upwards by the provision of a triode type T 1000–1 with an anode dissipation of 1000 W. This tube is particularly interesting for manufacturers of capacitive radio-frequency generators, such as are used for dielectric heating of all kinds of plastic materials.

Table I lists the preferred data of this tube for operation of this kind, while Fig. 209 shows an X-ray photograph of the tube itself. Its simple, robust design is obvious at a glance, and is the best guarantee of reliability in industrial service. It goes without saying that this tube also gives excellent results when employed as a class B or C amplifier in radio transmitters. Full details of its performance are given in the latest issue of the Electron Tube Handbook.

Development of the largest size tube at present made, type BT 50–1, has been completed; the tube has already been employed with success in large transmitting stations. The vapour-cooled model of this tube, in which case it is known as the BTS 50–1, has also attracted the attention of manufacturers of industrial generators. Fig. 210 shows one of these tubes in a 100-kW r.f. generator built by Brown Boveri. Vapour cooling has proved very effective indeed for the large transmitting tubes with external anode. For instance, in the Bisamberg broadcasting station near Vienna, the transmitters are still using their original tubes which, up to the end of December 1960, had completed over 5000 hours in service and were still perfectly serviceable.

2. Gaseous Discharge Tubes

Among the rectifier tubes for large transmitters the newly-developed high-voltage thyratron type TQ 8 was successfully introduced. Fig. 211 shows this tube in a rectifier set belonging to Radio Andorra, where it produces a d.c. voltage of 15 kV with a current rating of 42 A. The same type of tube is being employed in the rectifier sets for 250-kW medium and short-wave transmitters at present under

TABLE I

Typical preferred operating data of the triode type T 1000-1 used in r.f. generators

Class C oscillator, filtered anode voltage				
V_a D.C. anode voltage	V	5000	4000	3000
I_a Anode current (d.c.)	A	0·8	0·8	0·8
V_{gp} A.C. grid voltage	V	1025	975	925
V_g D.C. grid voltage	V	−650	−600	−550
I_g Grid current (d.c.)	mA	≈ 135	≈ 140	≈ 145
P_{gs} Grid control power	W	≈ 138	≈ 129	≈ 125
P_g Grid dissipation	W	≈ 45	≈ 46	≈ 47
R_g Grid resistance	Ω	4800	4300	3900
P_0 Anode output power	W	3100	2400	1670

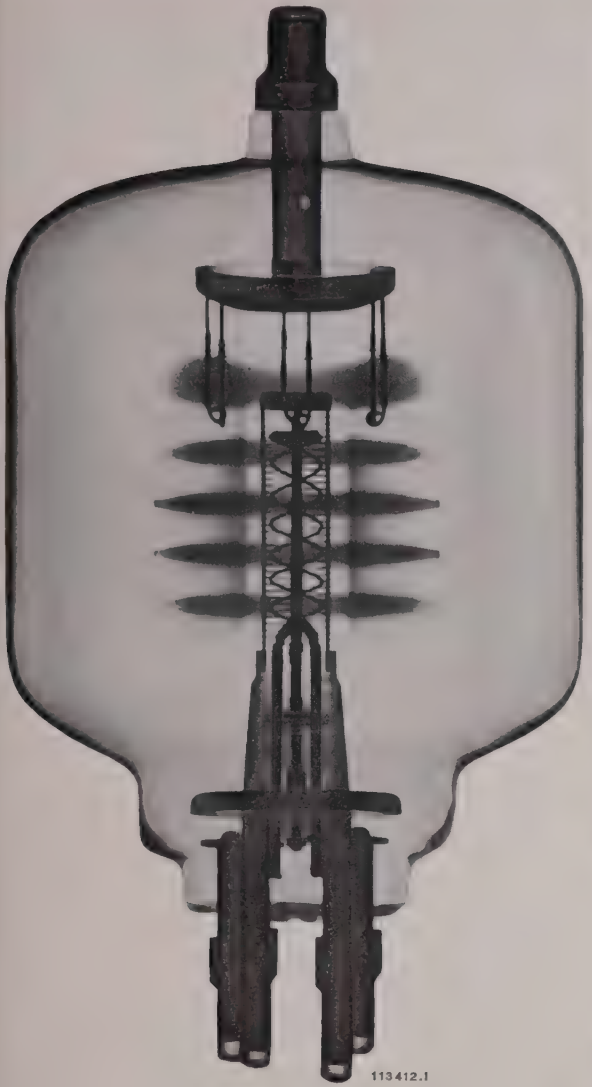


Fig. 209. – X-ray photograph of a convection-cooled transmitting triode type T 1000–1

Notable features are the strong cathode support and the solid, but simply designed anode bushing.

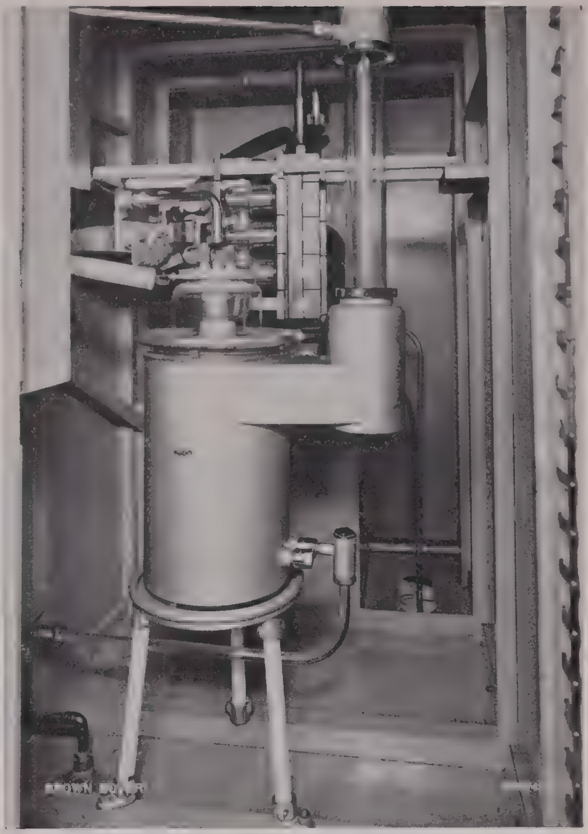


Fig. 210. – Industrial r.f. generator with a vapour-cooled triode type BTS 50–1, used for dielectric heating of synthetic fibres

construction. The Brown Boveri method of introducing the mercury filling, by what is known as the "pellet" method, has been established on a very wide basis, and enjoys considerable popularity with customers, since it dispenses with the long heating period which used to be necessary after the tubes had been transported. Furthermore, the tubes retain

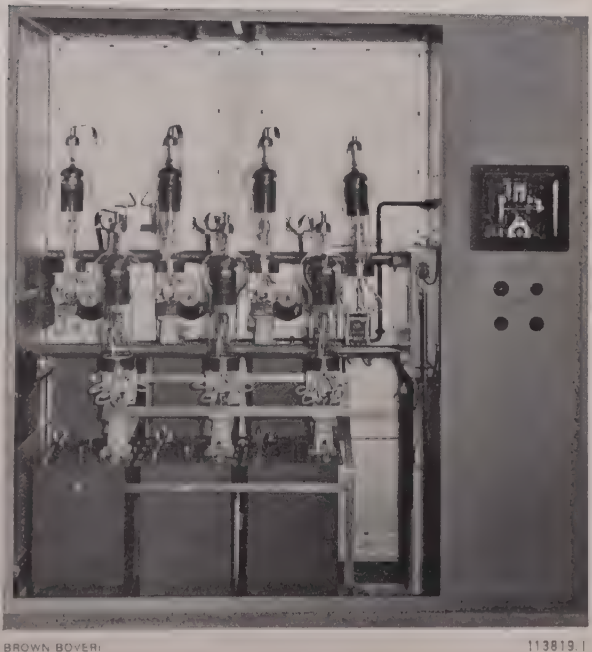
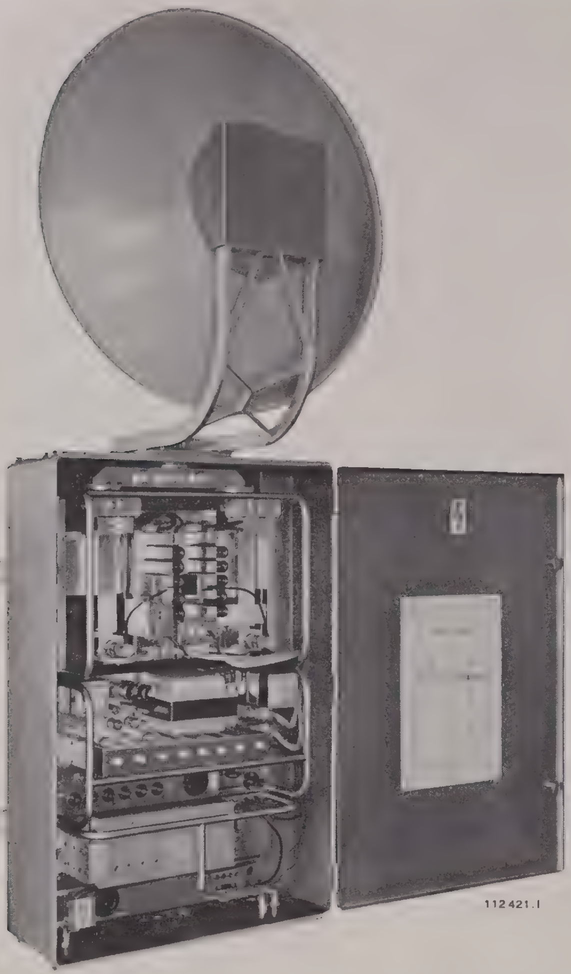


Fig. 211. – Rectifier set of the Radio Andorra transmitting station, with six tubes type TQ 8, producing an anode voltage of 15 kV with a d.c. rating of 42 A



BROWN BOVERI

Fig. 212. – Radio relay station type MT 1, for 6000 Mc/s, with a 70 cm diameter reflector

This transmitter-receiver station, with an output of 100 mW and an a.f. bandwidth from 30–54 000 c/s is ideal for high-grade music and speech transmission (multi-channel). A control circuit stabilizes the frequency of the transmitter and receiver klystrons to ± 90 kc/s ($\pm 1{\cdot}5 \times 10^{-5}$) at temperatures ranging from − 30 to + 50 °C. This extraordinarily good frequency stability and the high selectivity of the receiver permit the channel spacing to be reduced to 1 Mc/s with an i.f. bandwidth of 400 kc/s. The three sections of the chassis: microwave section, mains power pack and the transistorized receiver and i.f. amplifier are accessibly mounted on a hinged frame. The reflector can be attached direct to the case or connected to it by a r.f. lead up to 10 m long.

their clear envelope, even when they have been in service for a long time, backfires are avoided and the tubes are much easier to inspect.

The range of high-voltage diodes has been extended by the type DQ 45 tube which permits greater fluctuation by the a.c. anode voltage, all other performance data being the same as the type DQ 4. This is always an important factor when stabilization of the mains voltage is considered too expensive.

New tubes introduced into the range of medium-voltage thyratrons are the types TQ 5/3 and TQ 5/6. The characteristics of these tubes correspond to those of the types TQ 2/3 and 2/6, respectively, but they can be used for inverse voltages up to 5 kV. Admittedly the addition of argon is no longer feasible, so that these tubes can no longer benefit from the short heating time. But they can withstand almost all voltage peaks likely to be encountered in service, for example in welding equipment.

As a result of the high inverse voltage of the mercury-vapour thyratrons and their ability to withstand overvoltages, it is to be expected that they will continue to assert themselves for many years in this field, in preference to controlled semiconductor rectifiers.

B. High-Frequency Apparatus

The use of transistors and printed circuits demands the adoption of a completely new design technique for the apparatus, featuring extremely low power consumption and much smaller dimensions than hitherto. Transistors largely replace electron tubes. The established range of radio-telephone sets with the well-known types RT 5, 6 and 7, has been augmented by the types RT 16 and 17, the receivers of which are transistorized, with the exception of the r.f. input stage. The employment of printed circuits enables the transmitter and receiver of the RT 17 to be housed in a single casing, in spite of their being intended for duplex operation.

The increasing number of transmitting stations necessitates the adoption of much higher frequencies. A radio relay unit has now been developed for the 6000-Mc/s band which, with a relatively close channel spacing of 1 Mc/s and an a.f. bandwidth of 30—54 000 c/s, offers ample prospects for communication.

1. Radio Relay Equipment

The new radio relay set type MT 1 (Fig. 212) for the frequency band 6100–6400 Mc/s is ideal for multi-channel and music transmission. The frequency-modulated transmitter klystron with an output of 100 mW is stabilized by a special control circuit with a high-grade reference resonator. The extraordinarily high stability of ± 90 kc/s and the excellent selectivity of the receiver permit the use of a relatively close channel spacing of 1 Mc/s for a frequency deviation of ± 180 kc/s. The klystron of the receiver oscillator is frequency-stabilized as in the transmitter and is automatically tuned to the incoming transmitter frequency by the discriminator.

The i.f. and a.f. amplifiers are fully transistorized. With an aerial reflector 90 cm in diameter and with line-of-sight communication it is possible to cover up to 60 km with ample reserve to cater for fading (Fig. 213). With the a.f. channel from 30–54 000 c/s it is possible to transmit a music programme or up to nine speech channels, when used in conjunction with the transistorized multiplexer type MK 3.

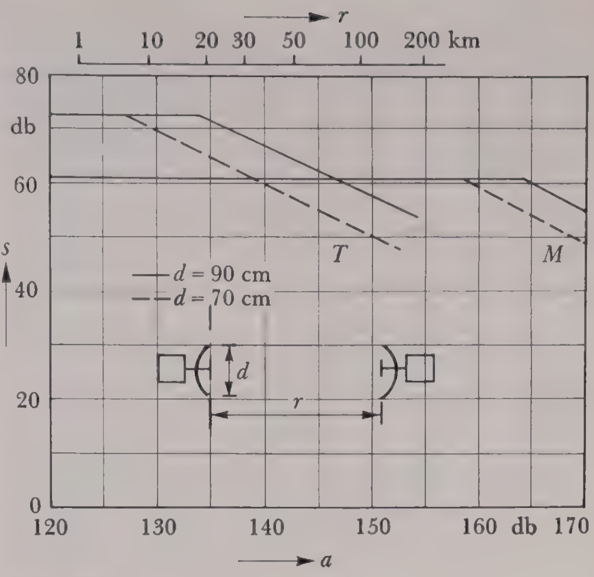


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Fig. 213. – Radio relay communication with the MT 1 set

M = Music transmission with 30–15 000 c/s

T = Multi-channel speech transmission in conjunction with the multiplex equipment MK 3

s = Signal-to-noise ratio in terms of the distance r and the path loss a. When transmitting music the distortion is less than 1 % at f = 1000 c/s.

For the frequency bands 156–174 and 450–470 Mc/s the existing station type RT 6 has been improved in design and largely converted to transistors, in which form it is known by the new designation RT 16. The external dimensions and the incorporation in a wall-mounting frame, as hitherto, have remained unchanged. The preliminary stages of the transmitter, and the i.f. and a.f. amplifiers of the receiver are now transistorized. The two triodes in cascode connection in the r.f. part of the receiver increase the sensitivity by about 6 db. An interchangeable i.f. bandpass filter with the bandwidths 80, 120 or 180 kc/s permits channels to be spaced at intervals of 150, 200 and 300 kc/s. This small radio relay station, comprising transmitter, receiver and power pack, having an a.f. bandwidth from 50 to 54 000 c/s, like the MT 1, is suitable for transmission of music, multi-channel speech or control signals of all kinds.

2. *Multiplex Equipment*

The multiplex equipment type MK 3 described for the first time in the review of progress two years ago can handle six speech channels in the band from 300 to 36 000 c/s. Since then it has been employed and tested in a number of installations in practice in Finland, the Lebanon, Spain and Austria. For example, the Hidroeléctrica Española use two RT 6 stations and two MK 3 multiplexers to transmit a total of twelve a.f. channels for speech and teleoperation signals (Fig. 214). Fig. 215 shows this equipment, together with the RT 6 station, fitted in transportable cases for service in devastated areas. Notable features of this unit are the high reliability of the transistorized equipment and the low consumption of 20 W. Various supplementary units extend its scope. For instance, with an automatic attachment it is possible to connect up to six telephone subscribers by radio to an automatic exchange (Fig. 216).

3. *Mobile Radio Equipment*

The radio-telephones types RT 5 and 7 have continued to render excellent service under all imaginable conditions. The transmitter and receiver of the new set type RT 17 are now housed in a single casing (Fig. 217). The transistorized power pack running off a battery supply at 6, 12 or 24 V is screwed to the back. When run off the mains an additional rectifier provides the necessary supply voltage. The set is

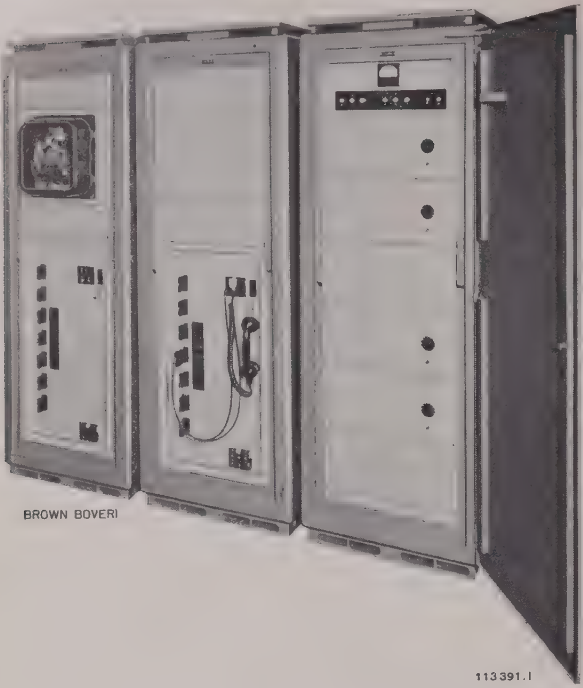


Fig. 214. – Radio relay station type RT 6, combined with multiplex equipment type MK 3, in a cabinet for floor mounting

The two RT 6 transmitter-receiver equipments contained in the cabinet on the right, in conjunction with the two MK 3 equipments in the left-hand cabinets, are capable of transmitting 2 × 6 speech channels. In this installation, supplied to Hidroeléctrica Española, Madrid, tele-operation signals are superposed on the speech channels. The RT 6 radio station with MK 3 equipment offers interesting possibilities for employment by power undertakings. The fact that they are housed in the same type of cabinet as the normal tele-operation equipment greatly simplifies planning, installation and operation.

intended for duplex operation with a transmitter output of 10 W in the frequency bands 68–88 and 156–174 Mc/s, and 5 W in the 460-Mc/s band. By means of a special cascode circuit with two triodes at the receiver input the sensitivity in the 160-Mc/s band is increased to 0·3 μV for a signal-to-noise ratio of 20 db. Compared with the usual sensitivity of about 0·6 μV, this improvement of 6 db corresponds to a four-fold increase in the transmitter output power, or a 40 % increase in the action radius in flat country.

4. *Auxiliary Devices*

The extensive list of auxiliary devices for use with radio relay sets and radio-telephones provide facilities for the following:

Selective calling of mobile or fixed stations

Manual or automatic interconnection with the public telephone network

Remote control of the station, either over a telephone line or by radio

Automatic changeover to a standby set

Scrambling of speech.

Fig. 218 shows the attachment used for connecting a radio subscriber to an automatic telephone exchange with the aid of an RT 5 or RT 17 station.

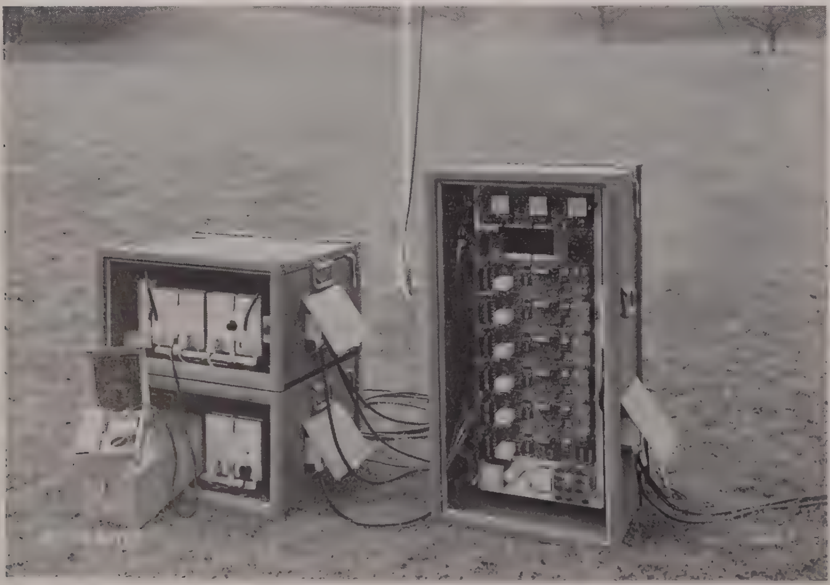
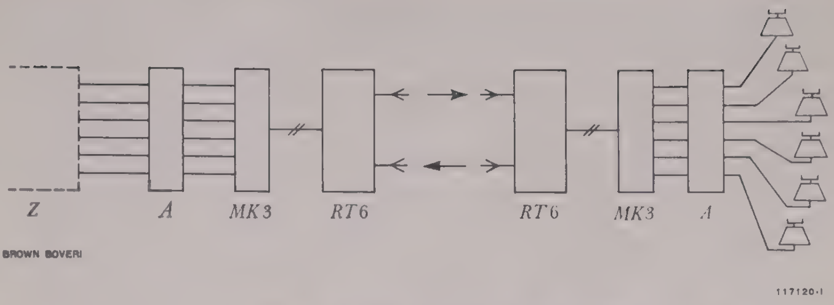


Fig. 215. – Radio relay station type RT 6 with multiplex equipment type MK 3 in a transportable casing

The Austrian postal authorities use mobile units of this kind for emergency service in areas devastated by catastrophe, when line communications are interrupted. Up to six links can be established at a time.

Fig. 216. – Inter-connection of six telephone subscribers with an automatic exchange by a RT 6-MK 3 combination

The automatic attachment *A* converts the criteria for dialling, interconnection, calling and tariff charges for handling by the radio channel. Z = Exchange.



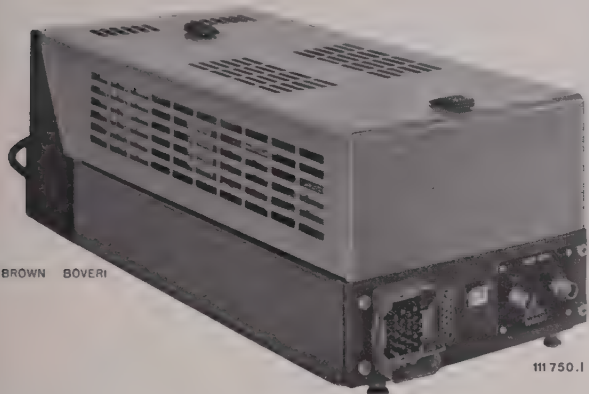


Fig. 217. – Transmitter-receiver type RT 17, battery or mains-fed

This set is designed for duplex operation in the 80, 160 or 460 Mc/s bands, producing an output of 10 or 5 W. The receiver is transistorized, except for the two r.f. stages which, connected in cascode, have the high sensitivity of 0·3 μV at 160 Mc/s. For mains operation the built-on transistorized power pack is replaced by a separate mains power pack.

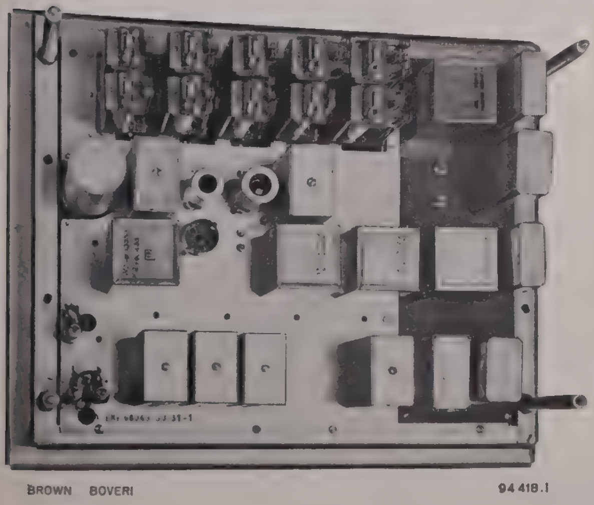


Fig. 218. – Telephone attachment

This attachment is used for radio interconnection of a telephone station to an automatic exchange in conjunction with an RT 5 or RT 17 transmitter-receiver station. In addition to the dialling, calling and interconnection criteria, this attachment also transfers the tariff pulses to the radio channel.

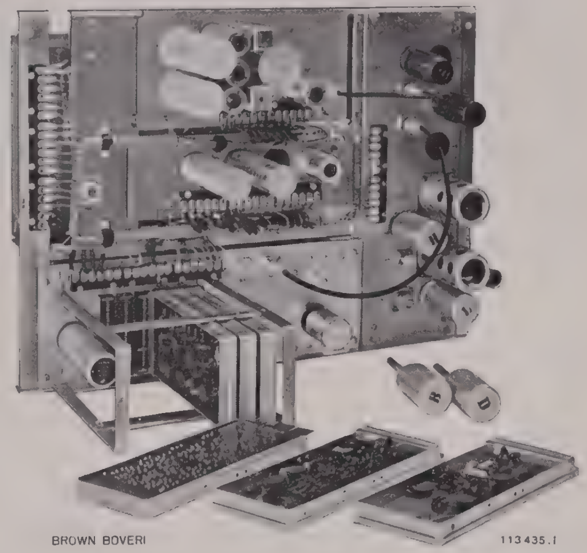


Fig. 219. – Driver stage for v.h.f. and television sound transmitters

The FM oscillator is phase stabilized by a quartz crystal in a transistorized divider circuit. The dividers are easily interchangeable printed circuits. The frequency response and distortion comply with the strict requirements of the band from 30 to 15 000 c/s. The r.f. output of appr. 4 W is sufficient to drive the power stages of the Brown Boveri v.h.f. and television sound transmitters.

5. Driver Stage for Frequency-Modulated (FM) Transmitters

The principles of the radio relay equipment were adapted for the design of a frequency-modulated driver stage for v.h.f. radio and television sound transmitters. The severe stipulations regarding the quality of transmission and frequency stability are fulfilled by a special FM oscillator, whose frequency is stabilized by a quartz crystal in a frequency divider circuit. In the circuit sketched in Fig. 219 the quartz crystals determining the frequency of the driver stage can be replaced by the line and video carrier frequencies, enabling the interval of 5·5 Mc/s to be accurately maintained between the video and sound carriers. The quartz stabilization of the oscillator frequency is performed strictly in phase; the tolerance for the transmitter frequency in the temperature range from 0 to 50 °C is $\pm\, 0{\cdot}5 \times 10^{-5}$.

C. Transmitters

1. Medium-Wave Transmitters

Among the various 25-kW transmitters taken into service during the past two years, the San Salvador station of the Portuguese National Broadcasting Company is worthy of special mention. In it two units operate in parallel to produce a total output of 50 kW (Fig. 220). The result of constantly reducing the space occupied by stations and the prices of the equipment, is that the comparatively higher cost of a duplicate transmitter becomes more and more acceptable, in view of the greater dependability and the simplified maintenance. For this reason the majority of new medium-wave transmitter stations are being built with duplicated equipment.

A newly developed 50-kW transmitter, which can be controlled from the front panels without any desk, has been supplied to All India Radio, for their Trichy station. Inside the cabinets sufficient space is available to permit the incorporation of programme monitoring equipment and instruments, the entire transmitter block being a complete installation requiring no external attachments (Fig. 221).

Prominent among the major contracts handled is the Bisamberg transmitting station of the Austrian Radio Network (Fig. 222). This is a rebuilt version of the former 100-kW station destroyed during the war. The installation is remarkable for a number of reasons. Firstly the progress achieved in the design of transmitting equipment is clearly illustrated by the fact that the space which used to house a single 100-kW transmitter now accommodates four 120-kW transmitters, which normally operate in pairs in parallel, emitting two different programmes. In this station Brown Boveri employed vapour cooling of the tubes for the first time, which in addition to contributing to a simpler and neater layout also utilizes the dissipated heat in the central heating system of the large group of buildings. The programmes are emitted from a pair of aerial masts with intermediate insulation, arranged with an

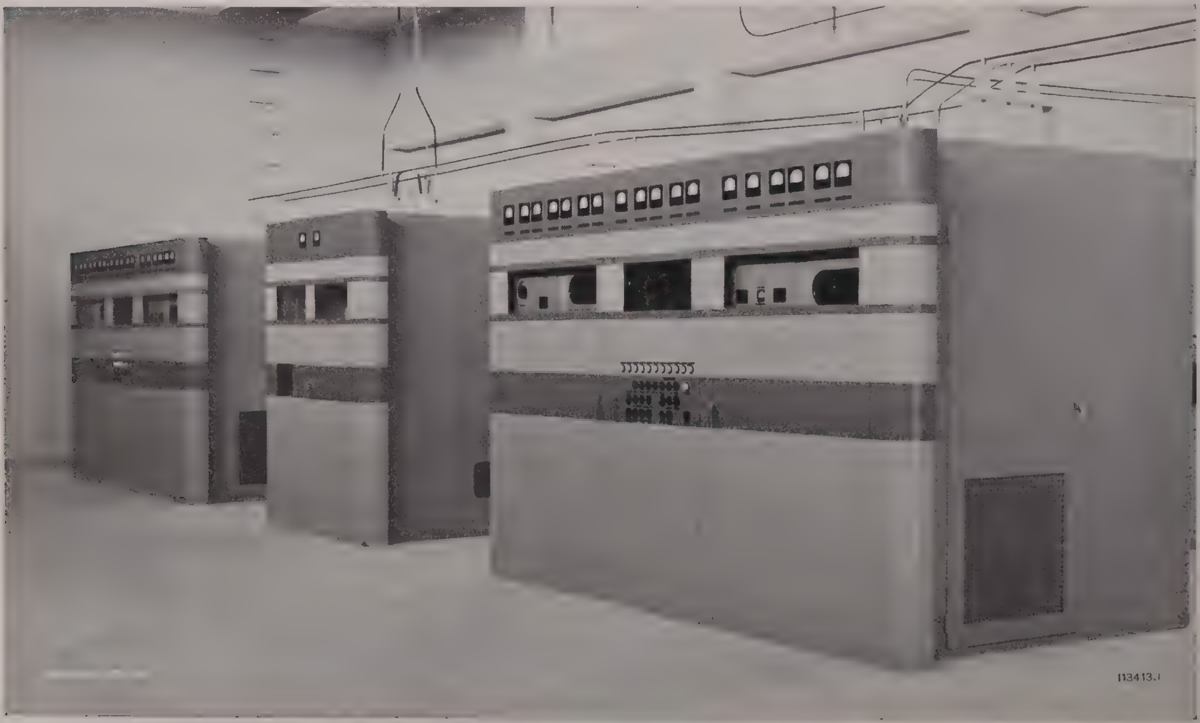


Fig. 220. – Two 25-kW medium-wave transmitters in parallel at San Salvador, Portugal

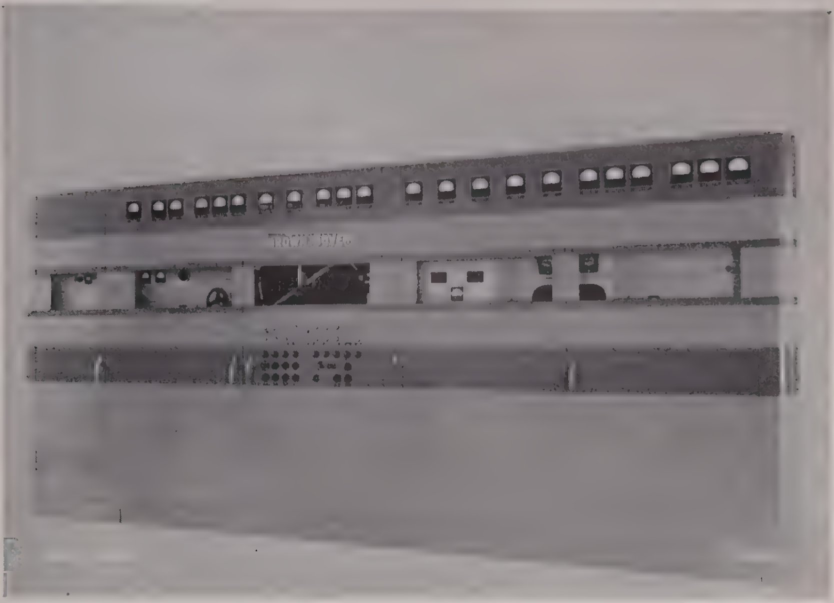


Fig. 221. – A 50-kW medium-wave transmitter

appropriate matching network for feeding at the foot or at the insulated junction. By regulating the input ratio between the foot of the mast and the junction point it is possible to obtain an optimum radiation characteristic for each aerial, thereby achieving the maximum possible zone free from fading. In spite of the difficulties involved, the south mast was also equipped to enable the two programmes to be transmitted simultaneously from the same mast in an emergency, with complete decoupling. In this case the whole height of the mast acts as an undivided radiator for the lower frequency while for the higher frequency the favourable double input remains unchanged. The installation is very popular, not only on account of its high technical quality, but also because every effort was made to obtain a pleasing and representative appearance without going to a great deal of extra expense.

The tendency towards higher outputs is constantly apparent. Newly designed, vapour-cooled 250-kW transmitters are at present being manufactured. The first unit of this type will soon be installed at Beromünster by the Swiss Postal Authority; two others are for shipment to South Korea, where they will operate in parallel.

2. Short-Wave Transmitters

As in previous years a large number of 1 to 10-kW transmitters have been placed in service in all parts of the world. The paralleling device which enables two 10-kW transmitters to attain an output of 20 kW

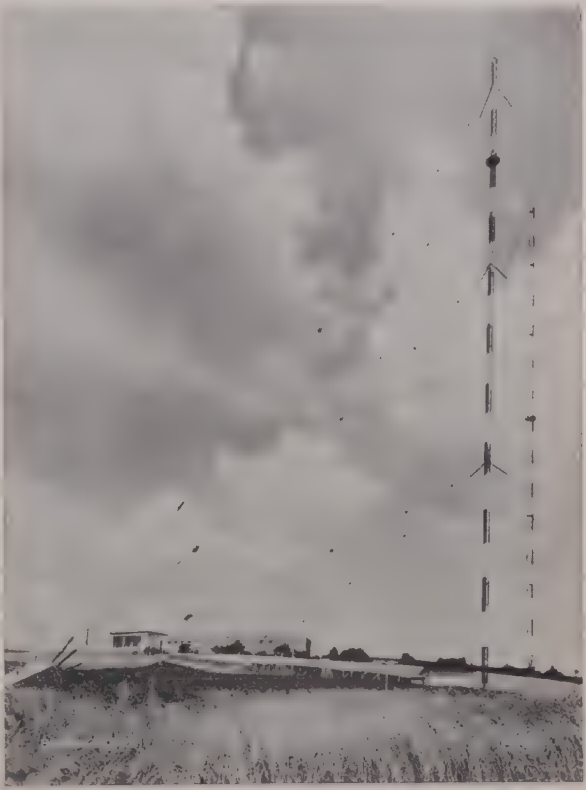


Fig. 222. – View of Bisamberg transmitting station near Vienna, with two pairs of 120-kW medium-wave transmitters

In the event of the rear aerial mast breaking down, the near mast can be used to transmit both programmes simultaneously.

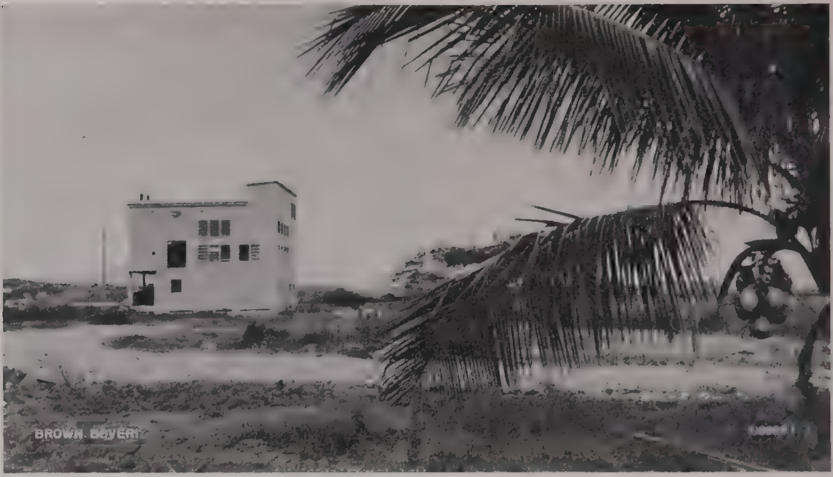


Fig. 223. – Short-wave station at Rio de Janeiro, with a 100/10-kW transmitter

in parallel has been re-designed in the meantime. It is now much simpler to match all feeder impedances likely to be experienced, so that wide disparity in the impedances of the feeders no longer causes any difficulty during tuning and commissioning.

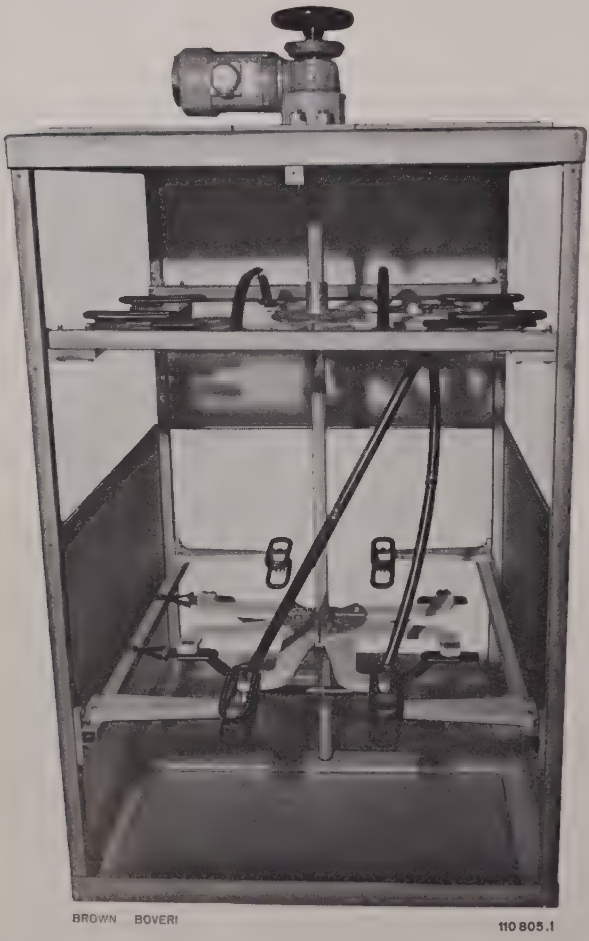


Fig. 224. – Aerial changeover switch for a telephony carrier power of 500 kW and 300-ohm feeders

Fig. 223 shows the 100-kW short-wave transmitter of Radio Tupi, Rio de Janeiro, which is equipped with a system of switchgear enabling it to operate with an output of 10 or 100 kW, as desired. Further 100-kW transmitters came into service at the Cairo station of UAR Broadcasting and at Rufisque in the Republic of Senegal. At the moment four other similar stations are being erected. Higher outputs are also being stipulated for short-wave transmitters. Orders for two 250-kW units are on hand at the moment.

The numbers of transmitters and aerial arrays in short-wave transmitting centres is continually increasing. Whereas it is no great problem to effect all possible interconnections between transmitters and different aerials in the smaller installations, extensions often lead to unforeseeable conditions. Then it is usually preferable to reorganize the feeder system and the switchgear for it, provided this is feasible and, in new stations in particular, to make sure from the start that all such changes of connections can be incorporated in a properly organized system, even if the installation should later be extended. Maximum flexibility is afforded by the cross-bar selector system, by means of which any aerial array can be connected to any of the transmitters.

For low outputs a coaxial system occupies the minimum space and is so arranged that it can be

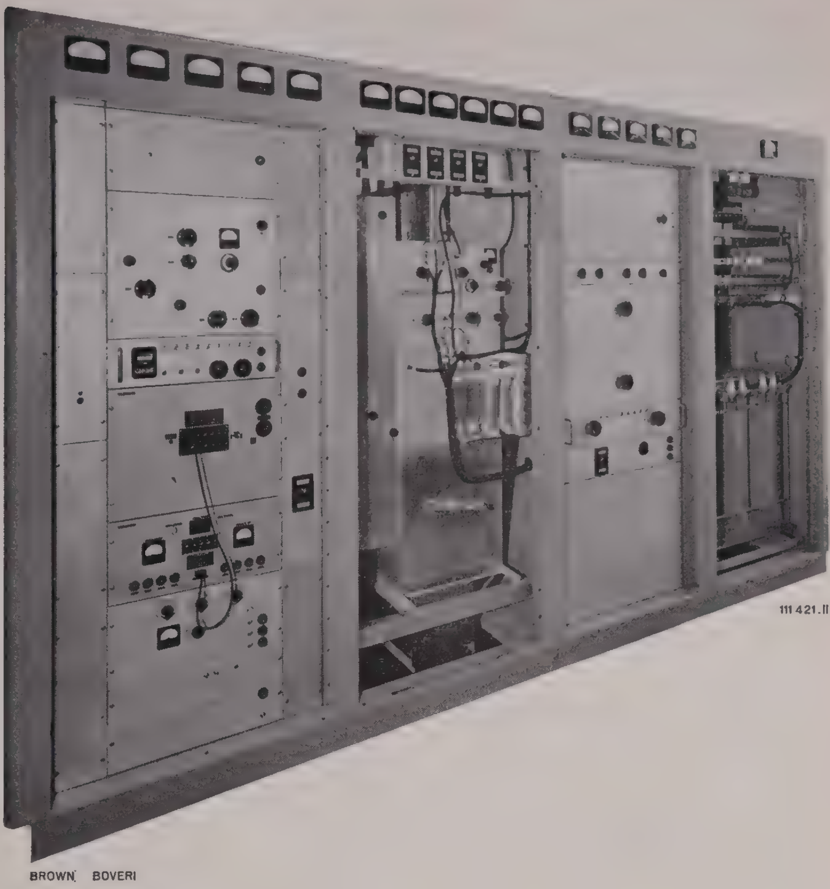


Fig. 225. – Television transmitter (with front doors removed) for 10-kW video power and 2-kW sound in band I

constructed for any number of aerials and transmitters. It may be used for telephony carrier powers up to 10 kW, or telegraphy powers up to 20 kW. In ground-to-air radio-communication installations, where several small transmitters are concentrated in a small space, the system has been used on a number of occasions.

The increase in the output powers has also necessitated the development of a larger switch, as shown in Fig. 224, designed for a carrier power of 500 kW. This switch is designed according to the same principles as the 100-kW switch, which has been supplied in large numbers. It fulfilled the strict acceptance conditions regarding electric strength and temperature rise due to the passage of current stipulated by an American client. This switch, designed as a separate block for use with a cross-bar system, offers the advantage of not being bound by the final capacity of the installation, because the switchgear for any transmitters or aerials subsequently installed can be added without difficulty, while maintaining the universal nature of the distribution facilities.

3. Television Transmitters

The range of television transmitters has been extended upwards by the addition of a 10-kW unit for band I (Fig. 225) and an 8-kW unit for band III. For the latter band a 4-kW transmitter will be available shortly. Based on the experience gained with earlier models, these transmitters are notable for their compactness and for the fact that the vestigial sideband filter of the video transmitter is now an organic part of the output stage and no longer combined with the diplexer. This greatly simplifies the design, and particularly control. Having regard to coloured television in the future, a new frequency-modulated driver stage has been brought out (see also page 151) which ensures that a fixed, whole-number ratio is maintained between the line frequency of the picture and the difference between the frequencies of the video and sound transmitters. Two

-kW band I transmitters, operating in parallel, will soon be taking over from the old television transmitter of the Swiss Post Office on the Uetliberg, near Zurich. Other transmitters have been ordered by the Norwegian postal authorities.

D. Tele-operation Equipment

1. Cyclic Digital Telemetering Equipment and Pulse-Code Remote-Control Equipment

The newly-developed equipment dealt with in this section was part of the programme covered by the evolution of the Brown Boveri electronic system[1] and is typically representative of the tele-operations range of equipment belonging to this system. Like the other ranges, it is designed on the "building-block" principle, the active elements of which are almost exclusively transistors.

The information handled, whether in the form of measurands, messages or commands, is converted into numerical form, i.e. as a sequence of different "Yes–No" states, which appear as pulse trains.

Cyclic digital telemetering is a further development of the system of rapid-cyclic telemetering based on an analogue principle, which was introduced with conspicuous success about eight years ago. The advantages of the new digital system are that it permits greater accuracy in measuring and transmission (± 0·5%), and that it occupies a much narrower bandwidth, which no longer affects the accuracy of the system but is only a function of the speed of transmission, e.g. 240 c/s for 12 measurands per second.

The measurand currents which have to be transmitted (0–5 mA) are converted cyclically into pulse trains. The code used for transmission—a straightforward binary code with eight digits—is augmented by a supplementary digit to improve the reliability of transmission. These pulse trains are then transmitted over wire, radio or power line carrier links by frequency shift. At the receiving end the coded measurands are conveyed cyclically to the associated storage registers. The reading can then be indicated numerically, or by d.c. instruments for 0–5 mA. In the latter case the direct current is obtained by digital-to-analogue conversion. Measurands can also be added arithmetically, without any additional error being caused by the addition.

The digital method of transmitting measurands complies with the severe conditions imposed by modern systems and will help to consolidate the position of Brown Boveri telemetering equipment on the market.

The pulse-code remote-control system represents a completely new approach to the problems of remote control. The equipment is also transistorized, relays only being employed for the input and output of signals and commands for the unit.

The principle of contactless switching allows a very high processing and transmission speed to be attained in spite of the fact that the number of monitoring functions is much larger than in relay or selector-operated remote-control systems. The incoming command is first encoded and stored, the desired receiving station being selected by a pilot code. Next the pulse train representing the command is transmitted by means of a '4 from *n*' code, with $n = 8$, 12 or 16, depending on the extent of the installation. On arrival at the receiving end the code digits are counted, stored, re-sampled and transmitted back to the transmitting end for the parity check.

Should individual pulses be missing, or severely distorted due to interference during transmission, the counting and parity check elements come into action and cause the whole process to be repeated. When the pulse train has been properly received, an executive command is imparted which, following further checks at the receiving end, allows the action to be performed or the signal to be transmitted. This is acknowledged by a signal sent back to the point of initiation. The whole process takes about 0·3 s.

Owing to the large number of checks and the employment of the frequency-shift principle for transmission of the pulse trains, the reliability is extremely high. For the speed mentioned above, the total bandwidth required is 240 c/s.

The remote-control unit proper is supplemented by two attachments, marketed for the first time by Brown Boveri. The first is a chronological signal memory unit, the other a device for printing out signals received.

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[1] See chapter III B 1 of this issue, and No. 10/11, 1960 of the Brown Boveri Review.

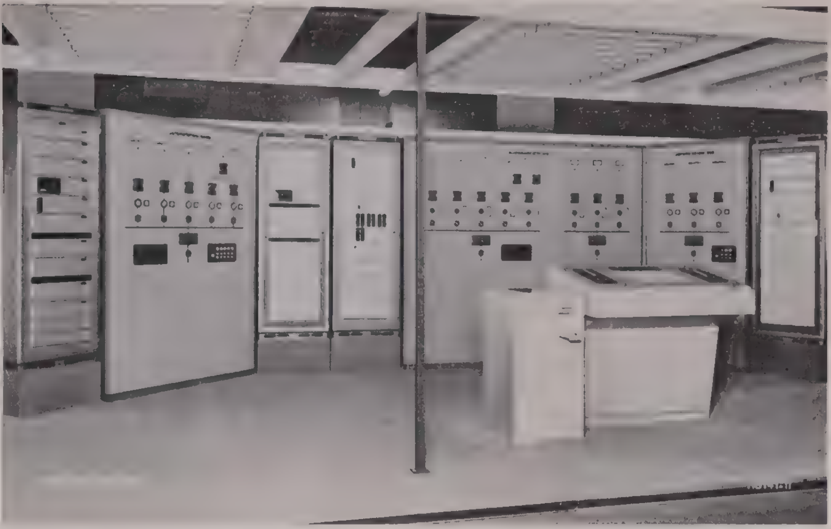

Fig. 226. – Remote control and indication equipment combined with digital cyclic telemetering

(Exhibited at Interkama, Dusseldorf, 1960.)

On the right is the control desk with selector control, while on the left is the printer for recording incidents with the time of occurrence.

The first of these is usually located in the remote-controlled station, where it stores the signals arriving at that station in the correct sequence, with a resolving power of 5 ms. These are then transmitted with the system's time constant of 0·3 s.

The second attachment unit consists of a decoder and an electro-mechanical printer, preferably in the form of a line printer. The decoder produces a pulse train from the executive pulse emitted by any output relay of the remote-control system and the coded time signals emitted by an electronic clock; this message is then conveyed to the printer and each command is represented by a row of digits. The instant at which a command is executed or an acknowledgement signal is received is recorded to the hour, minute and second.

The digital system of acknowledgement and remote control exceeds the bounds of normal remote-control equipment and, particularly in combination with the cyclic digital telemetering equipment is capable of performing duties on an unprecedented scale in large tele-communications installations.

A prototype information transmission system of this kind, complete with telemetering and remote-control equipment, supplemented by various devices, was exhibited at the International Congress and Exhibition for Instrumentation and Automation (Interkama) held in Dusseldorf in October 1960 (Fig. 226). Batch production of these new units will commence in the current year.

2. *Pulse-Transmission and Protective Equipment*

The pulse-transmission equipment which has been successfully built by Brown Boveri for a number of years, employing the frequency-shift principle, has been radically revised as part of the change to the "building-block" principle embodied in the Brown Boveri electronic system.

New circuits were devised, utilizing exclusively semiconductors, with which a further improvement can be effected in the quality of transmission, as regards distortion of the pulses, signal-to-noise ratio, and in the versatility of the equipment itself.

The units consist of standardized tiers incorporating sub-units (with heavy electrical components, such as relays, contactors, etc.) and printed circuits carrying the light electronic components, and for plugging into the tier.[2]

The new series of units comprises three distinct types of devices:

Pulse-transmission units based on the principle of frequency modulation are mainly used for the transmission of pulses from telemetering transmitters, teleprinters, remote-control equipment, etc. The normal design occupies 120 c/s, as laid down by CCIF, and, permits a keying speed of 50 Bd. This can, however, be appreciably increased if several CCIF channels are occupied.

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[2] T. Ernst: Design principles of the Brown Boveri electronic system. Brown Boveri Rev. 1960, Vol. 47, No. 10/11, p. 670–5.

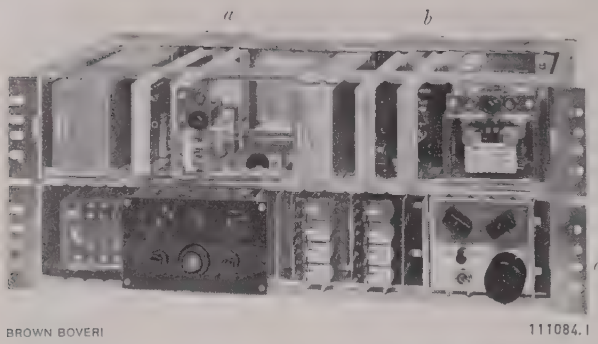

Fig. 227. – Line protection relaying unit

Transistorized transmitter-receiver unit with frequency shift for a.f. transmission over a telephone or signal wire, or via multi-purpose power line carrier link.

a = Signal transmitter
b = Signal receiver and evaluator
c = Test and interconnection unit for line protection, adaptable to the different kinds of protective relays

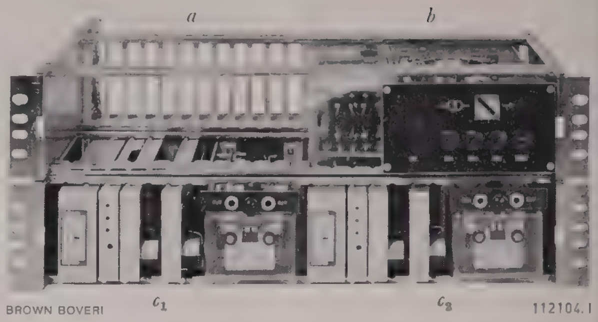

Fig. 229. – Remote tripping channel, receiver

Transistorized receiver and evaluator for a.f. frequency-shift signals, duplicated to increase the reliability. The interconnecting unit only passes the tripping signal on to the associated line breaker when both channels pick up at the same time.

a = Spare space
b = Testing and interconnection unit for remote tripping channel
$\left.\begin{matrix}c_1\\c_2\end{matrix}\right\}$ = Signal receiver, in duplicate

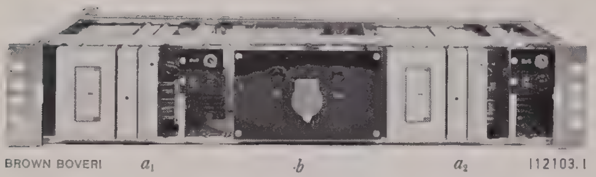

Fig. 228. – Remote tripping channel, transmitter

Transistorized a.f. transmitter with duplicated frequency shift to increase reliability. For transmission over a telephone or signal wire or via a single-purpose power line carrier unit specially reserved for this task.

$\left.\begin{matrix}a_1\\a_2\end{matrix}\right\}$ = Signal transmitter, in duplicate
b = Testing circuits

For transmission systems which have to operate with positive and negative pulses, a three-point frequency-shift unit is also made, having a central, steady-state frequency and two working frequencies, one above and one below.

Line protection relaying equipment (Fig. 227) is employed for transmitting tripping pulses to the breakers in the event of a fault on high-voltage power lines. The main feature of these units is their ability to operate rapidly and reliably when the transmission line is disturbed. By employing specially developed discriminator circuits it is possible to achieve transmission times of 20 ms with a total bandwidth of 180 c/s, and with a signal-to-noise ratio of about 4–5 db. Supplementary monitoring and testing devices assure a high degree of reliability.

The remote tripping channel (Fig. 228 and 229) is primarily used when devices protecting transformers, such as Buchholz or differential relays, have to actuate circuit-breakers situated some distance from the transformer, for reasons associated with the layout, for instance. The relaying equipment then transmits the tripping impulses from the protective devices to the breakers concerned. In order to avoid the breaker being tripped unnecessarily by disturbances on the transmission path, the relaying equipment must possess a high degree of insensitivity to such disturbances.

To comply with these severe requirements, two separate frequency-shift channels are employed, both combined in a single unit. These occupy a total bandwidth of twice 180 c/s, their electrical design being similar to that of the equipment used for line protection. The breaker is only tripped when both channels pick up simultaneously. The transmission time is 20 ms and the permissible signal-to-noise ratio approximately 1 db. The monitoring and testing devices are the same as for the line protection equipment.

A fundamental consideration in the design of these units was that maximum uniformity should be achieved in their parts. For example, those of the transmitter are alike for all units. The same applies to the sub-units of the receivers for the line protection and remote-tripping devices. The filters are of the same design mechanically and electrically, and have the same characteristic impedance. This greatly rationalizes production and simplifies the storage of spare parts.

E. Particle Accelerators

Excellent results have been obtained with the mobile betatron for deep therapy with gamma and electron beams. The original model, which could only be used for fixed-field radiation, has in the meantime been developed into a universal unit for moving and fixed-field therapy, and is known as the Asklepitron 35. According to the recognized specialists in this sphere, this machine complies with all the important requirements of radiologists and is considered to be the best deep therapy unit now being built in the million-volt range. The advantage of moving-field irradiation over the classical fixed-field therapy is that the dose at the skin can be reduced while maintaining the dose at the tumour. With pendulum therapy for instance, the axis of radiation should always pass through the centre of the tumour, while a strip of skin is irradiated, the length varying with the angle of swing. The Asklepitron 35 performs this motion in the following manner (Fig. 230). The betatron unit proper (1) rotates at a constant, preset speed about its horizontal axis *a*. The bed *b* with the patient, connected to the betatron through the arm *c*, is thereby pressed lightly downwards against springs (2). The resultant downward motion is converted in an electronic circuit and utilized to control the vertical motion (3) of the betatron. The horizontal motion (4) of the bed along the rails is effected automatically by the arm *c*. Thus the axis of the beam intersects a constant point in space, at which the centre of the tumour *T* has to be positioned.

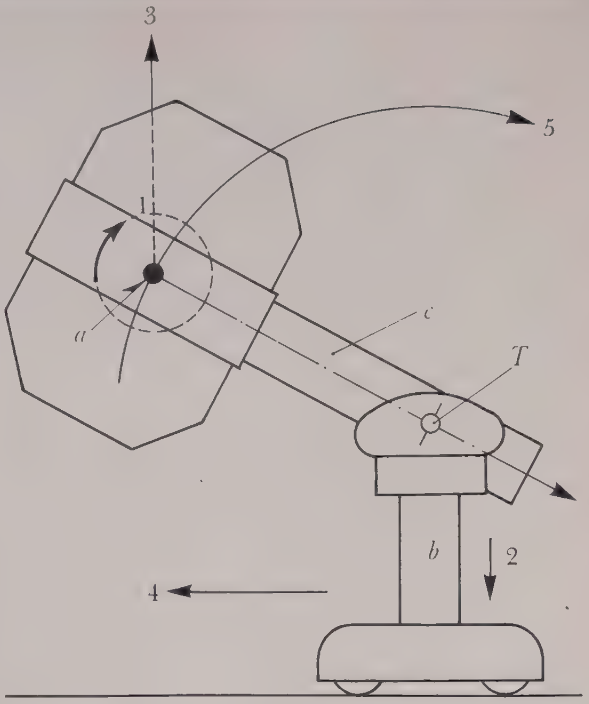

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Fig. 230. – Schematic diagram of the Asklepitron 35

For notation see text

The angle through which the beam axis may swing is variable between 30 and 210 °.

In addition to pendulum treatment, this type of betatron can be used for other forms of moving-field therapy. The bed can be rotated about a vertical axis by an electric motor, for rotational therapy. For other cases requiring fixed-field therapy the bed and betatron can easily be uncoupled from one another.

For accurate alignment of the patient with respect to the field of radiation, the following auxiliary devices are provided

- A built-in 125-kV, 200-mA diagnostic X-ray tube with a viewing screen,
- A mechanical front and back pointer indicating the axis of the high-energy therapeutic beam.

The first installation of this kind was taken into service towards the end of 1960 at the Montefiore Hospital, New York. At present twenty more installations with the Asklepitron 35 are in the course of manufacture, for commissioning between 1961 and 1963.

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